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Manure Use for Fertilizer and for Energy

Report to Congress

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Abstract

The Food, Conservation, and Energy Act of 2008 directed the U.S. Department of Agriculture to evaluate the role of animal manure as a source of fertilizer, and its other uses. About 5 percent of all U.S. cropland is currently fertilized with livestock manure, and corn accounts for over half of the acreage to which manure is applied. Expanded environmental regulation through nutrient management plans will likely lead to wider use of manure on cropland, at higher production costs, but with only modest impacts on production costs, commodity demand, or farm structure. There is widespread interest in using manure as a feedstock for energy production. While current use is quite limited, expanded government support, either direct or indirectly, could lead to a substantial increase in manure use as a feedstock. However, current energy processes are unlikely to compete with fertilizer uses of manure, because they leave fertilizer nutrients as residues, in more marketable form, and because manure-to-energy projects will be most profitable in regions where raw manure is in excess supply, with the least value as fertilizer.

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Summary

Animal manure can be used as a fertilizer, and it can improve soil quality. Manure can also be used as a feedstock for energy production. But excessive concentrations of manure, either in storage or in land application, can create environmental risks, and farmers are facing increased regulation of their manure management practices.

What Is the Issue?

The Food, Conservation, and Energy Act of 2008 directed the Department of Agriculture (USDA) to prepare a study that would evaluate the role of animal manure as a source of fertilizer, and its other uses. The study was to provide:

1. *a determination of the extent to which animal manure is utilized as fertilizer in agricultural operations by type (including species and agronomic practices employed) and size;*
2. *an evaluation of the potential impact on consumers and on agricultural operations (by size) resulting from limitations being placed on the utilization of animal manure as fertilizer; and*
3. *an evaluation of the effects on agriculture production contributable to the increased competition for animal manure use due to bioenergy production, including as a feedstock or a replacement for fossil fuels.*

Animal manure is used as a crop fertilizer and soil amendment, but it can pose environmental risks when stockpiled or applied in excessive amounts. Federal, State, and local governments have responded to the environmental risks with regulations and conservation programs, and some State and local governments have also initiated lawsuits against livestock operations, claiming damages to water resources from manure. Efforts to comply with regulations impose costs on certain livestock operations and will likely lead to changes in manure use on those operations.

There is also increasing interest in using manure for energy production. Methane can be captured from the biogas in manure and burned for electricity generation, while manure can also be burned directly as a feedstock in combustion processes. This report assesses current patterns of use of manure as fertilizer and evaluates the likely impacts of emerging environmental regulations on manure use. The report also assesses current efforts to use manure for energy production and evaluates the impact of bioenergy investments on manure's use as fertilizer.

What Did the Study Find?

About 15.8 million acres of cropland, equivalent to about 5 percent of all U.S. cropland, are fertilized with livestock manure. Corn, which is planted on about one-quarter of U.S. cropland, accounts for over half of the land receiving manure. Patterns of manure use are driven by the agronomic needs of crops and by transport costs, which limit the distance that manure can be

moved and create close links between types of livestock and certain crop commodities. Each favors the application of manure to corn.

Most manure applied to corn comes from dairy and hog operations. Manure from poultry and cattle feedlot operations is drier and less costly to transport, and is therefore often removed from the farm and shipped to other operations. Because broiler production is concentrated in the southern United States, crops like peanuts and cotton rely heavily on broiler manure when they use manure fertilizers.

Large livestock operations are increasingly required to have nutrient management plans, which require balancing nutrient applications with the nutrient utilization of crops. Compliance with the plans can raise farm costs. Estimated costs vary sharply with the degree to which excess manure needs to be disposed of and the willingness of nearby farmers to accept manure for application to their cropland. A low willingness to accept among nearby farmers means that livestock producers will need to transport excess manure much farther for crop application. With a limited willingness to accept manure (defined as 20 percent of nearby farmers), we estimated that production costs, including those for manure management, would likely rise by 2.5-3.5 percent for large operations.

Such increases are unlikely to alter the emerging structure of livestock production, where large operations have substantial cost advantages over small operations. They are also unlikely to lead to substantial declines in production and consumption; the resulting percentage retail price changes would be less than the cost changes noted above because farm costs are only a fraction of retail costs, and retail demand for meat and milk is relatively insensitive to price changes. As a result, expanded regulation through nutrient management plans will likely lead to wider use of manure on cropland, at higher production costs, with little impact on the size structure of farming operations.

Manure-to-energy projects are not currently in widespread use. Digester systems, including those planned or in construction, cover less than 3 percent of dairy cows and less than 1 percent of hogs. The single operating combustion plant utilizes litter from 6.6 percent of U.S. turkey production, while an idled plant in California could utilize manure from about 3 percent of fed cattle.

Manure-to-energy projects may allow farmers to realize benefits from avoided purchases of electricity, from selling electricity, or from selling manure to generating plants, but few realize enough savings to justify the expense. But because such projects use existing resources, they could provide society with benefits if manure replaces newly mined fossil fuels in energy production, and if methane, a greenhouse gas, can be captured. Those societal benefits have led to proposals to support manure-to-energy projects through State utility mandates (to purchase electricity from farms and to invest in renewable production sites), through subsidies for capital costs, and through direct subsidies and credits for energy production. Expanded support could lead to a substantial growth of energy applications for manure.

Currently envisioned manure-to-energy projects are not likely to impose substantive constraints on the use of manure as fertilizer. Many of the nutrients that are beneficial to crop growth remain after energy production. Nitrogen, phosphorus, and potassium nutrients remain in the effluent of the digester process, to be spread on fields. Combustion processes do consume the nitrogen nutrients in manure, but leave phosphorus and potassium in an ash residue that, because of its concentrated form, is less costly to transport than raw manure. In addition, manure-to-energy projects function in markets for fertilizer and energy, and will be most economic in those areas in which the acquisition costs of manure are lowest. In turn, manure acquisition costs will be lowest where manure is in excess supply, with the least value as fertilizer.

How Was the Study Conducted?

The report relies primarily on a large-scale representative survey of farms, the annual Agricultural Resource Management Survey (ARMS), which is the USDA's primary source of information on farm production practices and the financial condition of farm businesses and households. One phase of the survey (Phase II) focuses on operations that produce specific crops, and includes questions concerning land use and production practices for the crop, including manure applications. Recent Phase II surveys covered barley (2003), corn (2005), cotton (2003), oats (2005), peanuts (2004), sorghum (2003), soybeans (2006), and wheat (2004), which allows us to assess manure use and management practices for those major field crops.

Another survey phase (Phase III) provides data on farm organization and structure for all commodities, and it also provides data on manure production and management practices on selected livestock operations. Commodities covered include hogs (1998 and 2004), dairy (2000 and 2005), and broilers (2006). We supplement ARMS with data from other USDA surveys, including the census of agriculture, as well as databases developed by the Environmental Protection Agency (EPA), USDA's Natural Resources Conservation Service (NRCS), and the American Society of Agricultural and Biological Engineers (ASAE).

Introduction

The Food, Conservation, and Energy Act of 2008 (commonly known as the 2008 Farm Bill) directed the Department of Agriculture (USDA) to prepare a study that would evaluate the role of animal manure as a source of fertilizer and other uses. Specifically, the statute (Title XI, Section 11014) called for a study to provide:

1. *a determination of the extent to which animal manure is utilized as fertilizer in agricultural operations by type (including species and agronomic practices employed) and size;*

2. *an evaluation of the potential impact on consumers and on agricultural operations (by size) resulting from limitations being placed on the utilization of animal manure as fertilizer; and*

3. *an evaluation of the effects on agriculture production contributable to the increased competition for animal manure use due to bioenergy production, including as a feedstock or a replacement for fossil fuels.*

Manure is used widely as a crop fertilizer and as a soil amendment. It contains nutrients—such as nitrogen, phosphorus, and potassium—that facilitate plant growth, and manure can improve soil quality by neutralizing acidity, increasing organic matter, decreasing compaction, and increasing water-holding capacity. Manure can be deposited on cropland by grazing animals, but is commonly transported from animal confinement and manure storage facilities and spread on the ground or injected into it.

Manure is a substitute for commercial fertilizers, whose prices rose sharply in recent years along with prices for other products derived from fossil fuels and minerals (Huang, 2009). Nitrogenous commercial fertilizer prices doubled between 2000 and 2007, and then rose again by 62 percent between December of 2007 and September of 2008. Phosphatic commercial fertilizer prices rose by 115 percent between 2000 and 2007, and then rose by 177 percent between December 2007, and September 2008.[1] Prices for each receded to 2007 levels by the Winter of 2009, but the sharp price changes and likelihood of high future prices have kindled greater interest in manure fertilizers.

[1]U.S. Bureau of Labor Statistics, Producer Price Index (http://stats.bls.gov/ppi/#data).

Higher commercial fertilizer prices make manure fertilizers look more attractive. However, opportunities for widespread manure substitution are limited: manure can be costly to transport for even short distances, and some crops are far from sources of manure production. Moreover, manure may not have the precise combination of nutrients needed for specific crops and fields. This report details current patterns of manure use on crops and identifies factors that limit manure use.

Manure can also pose environmental and human health risks when stockpiled or applied in excessive amounts. Wastes can be transmitted from cropland to surface waters through the runoff of nutrients, organic matter, and pathogens from fields and storage; to ground water through the leaching of nutrients and pathogens; and to the atmosphere through the volatilization of gases and odors. Pollutants may originate at structures where animals are kept; at manure storage facilities such as tanks, ponds, or lagoons; or on land where manure is stored or is applied as fertilizer.

Because industrialized livestock production concentrates manure on limited land areas, some producers apply manure at intensities well above the agronomic needs of crops, thereby increasing pollution risks. Most also store manure prior to application, in pits and lagoons, posing environmental risks from seepage, flooding, or catastrophic failure. Manure odor is a persistent local issue, leading to the use of setback rules separating animal operations from residential areas.

Federal, State, and local governments have responded to manure's environmental risks with regulations and conservation programs. Federal and State regulatory initiatives require many large operations to develop and implement nutrient management plans (NMPs) that base nutrient applications on agronomic rates, and many operations will need to spread their manure over a much larger land base, or reduce manure production, in order to comply with their NMPs.

Compliance with NMPs imposes costs on large confined livestock operations, and has led to changes in manure use and management practices on many operations. To the extent that rules force manure to be spread over a larger landbase, they also spur interest in improved transport and application of manure as a substitute for commercial fertilizers. This report assesses the likely costs of such regulatory initiatives, as well as the responses that producers are taking.

State and local governments have taken other steps aimed at controlling manure production and application. California has enacted regulations in the San Joaquin Valley to protect heavily populated areas downwind from animal feeding operations, and has required many feeding operations in the Valley to obtain permits for manure discharges. North Carolina imposed a partial moratorium in 1997 on the construction of new hog farms in the State. Urbanizing development in each State has led to increased regulation of livestock feeding operations, and has also led to rising land prices, which have induced some livestock feeding to move to less dense areas.

Animal manure can also provide a source of fuel for heating and electricity generation. Dry manure has long provided heat and cooking fuel for rural societies, but the biogas from manure contains carbon dioxide and methane, greenhouse gases that remain in the atmosphere, trapping heat. Methane can be captured from biogas and burned for electricity generation (used on-farm or transmitted for use elsewhere through the electricity transmission grid), and it can be purified to yield pipeline-quality natural gas. Manure can also be shipped to centralized conversion and/or generation facilities. Growing environmental concerns, as well as long-term price increases for electricity, have led to growing interest in the use of manure for energy production. This report assesses current efforts to use manure for energy production, describes the barriers to further adoption, and evaluates the impact of bioenergy uses on manure's use as fertilizer.

Data Sources for this Study

This report relies on a large-scale representative survey of producers, the annual Agricultural Resource Management Survey (ARMS), which is the USDA's primary source of information on the financial condition of farm businesses and households and farm production practices. ARMS consists of enumerator-assisted surveys of farm operators, focused on their farm business and household. Administered jointly by the Economic Research Service (ERS) and the National Agricultural Statistics Service (NASS), it is conducted annually in three phases. Phase I is a screening questionnaire used to improve survey efficiency. Phase II, conducted during the fall of each year, aims at physical and economic data on production inputs, management practices, and commodity costs of production. Phase III, conducted in the winter following the reference year, focuses on farm income and expenditures, farm financial arrangements, and other characteristics of the farm business and farm household.

The Phase II surveys focus on operations that produce specific crops; a field planted to that crop is chosen at random for questions concerning land use and production practices, including manure applications. Phase II respondents also receive Phase III surveys, so the information on production practices can be linked to farm financial information. Phase II covers 1-2 crops in most years, with recent surveys directed to barley (2003), corn (2005), cotton (2003), oats (2005), peanuts (2004), sorghum (2003), soybeans (2006), and wheat (2004), which allows ERS to assess manure applications to those major field crops. The surveys are weighted so as to be nationally representative of each commodity.

Phase III surveys provide data on farm organization, finances, and marketing practices for all commodities (not just those covered in Phase II) and all farm types in the continental United States. Phase III usually contains several versions, with a commodity-specific livestock version in most years. Livestock versions elicit information on production and expenses, marketing and investment decisions, and production practices, including manure management decisions. Commodities covered include hogs (1998 and 2004), dairy (2000 and 2005), and broilers (2006).

ARMS data provide the primary source of information on manure production and use. We supplement ARMS with manure production estimates developed by the American Society of Agricultural and Biological Engineers and with livestock inventory and production data from other USDA surveys, including the census of agriculture. Large-scale USDA surveys do not yet provide reliable data on energy uses for manure.[2] For that information, we turn to databases developed by the Environmental Protection Agency (EPA) and USDA's Natural Resources Conservation Service (NRCS).

[2]Given its current sample size, ARMS will not include activities with small numbers of participants, such as on-farm energy uses of manure (for example, only about 100 dairy farms, out of 70,000 nationwide, currently use anaerobic digesters).

Linkages Among Livestock, Manure Production, and Crop Needs

Manure use is influenced by the size, product mix, and location of crop and livestock farms. In this section, we describe these structural elements and their impact on manure utilization.

Commodity production is becoming more specialized. Many crop operations have no livestock, and therefore no on-farm manure production. Some livestock operations specialize only in livestock, and forgo crop production entirely. The separation of manure and crop production raises the costs of using manure as a fertilizer since manure must be transported off the originating farm for application by crop operations.

Regional specialization also matters. Significant centers of large-scale livestock production now occur in regions—like the Southeast (poultry and hogs), the High Plains (fed cattle, dairy, and hogs), and the West (dairy)—where manure production exceeds the nutrient needs of nearby crops. Similarly, major grain production regions in the Corn Belt have seen a long-term reorientation away from livestock and toward feed grains (Hart, 2003). The greater geographical separation between livestock and crop producers, the higher the costs of transporting excess manure.

With the exception of the beef cow-calf sector, livestock production has been shifting to larger operations, as economies of scale in production provide larger operations with lower costs and better financial returns (MacDonald and McBride, 2009). But large-scale operations consolidate manure as well as animals in a confined space and can produce more than is needed to meet agronomic needs of nearby crops.

To illustrate the issues involved, we next use examples from milk production, hog finishing, broiler growing, and beef cattle feeding. We draw on ARMS Phase III for data on farm structure, while data on manure production and characteristics are drawn from standards published by the American Society of Agricultural and Biological Engineers (ASAE, 2005) [3]

Dairy

A lactating dairy cow produces about 150 pounds of manure a day, while a dry cow produces 83 pounds—about 25 tons of manure annually, including 330 pounds of nitrogen, 56 pounds of phosphorus, and 36 pounds of potassium.[4]

Farmers feed corn silage and grain to cows, and corn uses lots of nitrogen, so dairy farmers can take advantage of a natural cycle. If nitrogen were applied to corn at a rate of 125 pounds per acre, the farm would need 2.64 acres of corn to absorb each cow's as-excreted manure.[5] Dairy farmers also grow alfalfa and other forage crops and fertilize them with manure, but most of those crops take up fewer nutrients than corn and, hence, have greater land requirements to absorb each cow's as-excreted manure.

These acreage estimates are maximums, assuming no volatilization of manure occurs. As wet manure dries, some nutrients volatilize—nitrogen, for example, becomes airborne ammonia. Because volatilization reduces the amounts of nutrients remaining in stored manure, it also reduces the amount of crop-acres needed for spreading manure at agronomic rates, although it can then contribute to air pollution. The degree of volatilization varies widely with manure storage practices and local climate conditions.

Dairy production has expanded rapidly in the West, and California, Idaho, and New Mexico are now major producers, with significant areas

[3]We rely on the current standards, as revised in 2005. The revised standards are based on models of animal performance and dietary feed and nutrient intake.

[4]These are "as-excreted" estimates, which include both solids and liquids, with moisture estimated at 87 percent of the total, by weight (ASAE, 2005). Moisture percentages are 92 percent for fed cattle, 90 percent for finishing hogs, and 74 percent for broilers. These are averages, for specified typical production practices, and assuming that a cow is dried off for 60 days a year. Actual manure and nutrient production can vary with feed characteristics, the feeding regimen, breeding, and animal performance.

[5]Calves and heifers also generate manure, albeit at a much lower rate, so farms that keep them onsite would need more land. Farms with at least 1,000 cows in the herd accounted for 46 percent of milk production in 2008 (USDA/NASS, 2009).

of production also occurring in Washington, Arizona, Kansas, and Texas. Some large western dairies have no crop production, and about 16 percent of all U.S. dairy production now occurs on farms with no crop acreage. These operations may have to transport manure significant distances for crop applications.

Hogs

Today, most hogs are owned by integrators who provide contract growers with feeder pigs and feed and pay them to grow the pigs to market weight. While the integrator provides prepared feed for the hogs, growers in the Midwest usually also have a crop enterprise (corn, soybeans, and wheat are most common), and hog production yields low-cost manure nutrients as well as the fees paid by integrators.

A hog in a finishing operation will produce 10 pounds of nitrogen, 1.7 pounds of phosphorus, and 4.4 pounds of potassium in the 1,200 pounds of manure that it excretes annually on the farm, so an operation that finishes 6,000 hogs a year could need as much as 480 acres of corn, if no volatilization occurred and if it were to apply nitrogen to corn at 125 pounds per acre.[6] Soybeans and wheat take up fewer nutrients and so require more land.

The western Corn Belt, an area of intense crop production, is still a major center of hog production. But important production complexes are also located in North Carolina, Oklahoma, and Utah. Many growers in those States specialize in hog production—nationwide, 22 percent of market hog production occurs on farms with no crop acreage—and manure from these operations must be transported to crop farms.

Broilers

A broiler chicken produces 11 pounds of manure, on average, with 0.12 pound of nitrogen, 0.035 pound of phosphorus, and 0.068 pound of potassium, in the seven weeks that it is fed. A large-scale operation can produce 600,000 broilers in a year. With 72,000 pounds of nitrogen in the 3,300 tons of manure, a producer would need as much as 576 acres of corn at the application rates noted above, if no volatilization occurred.

Many broiler operations are specialized, with no crop production, and very few grow that many acres of any crop.[7] But broiler litter is relatively dry and thereby less costly to transport, and its high nutrient content gives it value. As a result, most litter is removed from the operation and spread on other farms. With most production in the South, broiler litter is used on crops like cotton and peanuts, and on bermuda grass, a nitrogen-thirsty grass used for grazing livestock, particularly beef cattle.

Fed Cattle

In a single year, a large cattle feedlot might fatten 35,000 cattle for slaughter. [8] Most are located in the High Plains, and they usually specialize in feeding— 68 percent of fed cattle production occurs on farms with no crop acreage. Nearby producers grow corn, alfalfa, grain sorghum, soybeans, and wheat, and cattle grazing is also popular on crop residues or grasses.

[6]The broiler, hog, and fed cattle estimates are for a "finished animal," covering the number of days that the animal is on the farm before being removed for slaughter.

[7]Forty percent of U.S. broiler production, and 45 percent of total poultry production, occurs on farms with no crop acreage.

[8]Our hog, broiler, and fed cattle herd and flock size estimates are taken from MacDonald and McBride (2009). We've chosen round numbers that are close to the median of the size distribution of production, where half of all sales/removals came from larger farms and half from smaller. They represent the size of farm from which a typical animal came.

A feedlot steer produces much less manure than a dairy cow (4.9 tons per year versus 22), in part because the steer doesn't usually spend a whole year in a feedlot. But when aggregated over the total number of animals (35,000) a large feedlot produces almost 172,000 tons of manure each year, with 1.925 million pounds of nitrogen, 0.256 million pounds of phosphorus, and 1.33 million pounds of potassium. A feedlot of that size, with that amount of nitrogen production, would need to find over 15,000 acres of corn for the nitrogen produced, or a greater acreage of other crops. Volatilization substantially reduces the aggregate amount of crop acres needed in the arid climate of the High Plains, but substantial quantities of manure solids must still be moved to cropland, where they are often tilled into the soil to provide more soil organic matter.

Use of Manure as a Crop Fertilizer

In this section, we assess the extent to which animal manure is used as fertilizer, as well as the conditions under which it is used. We first estimate aggregate use—the total acres of planted cropland in the U.S., and the share receiving manure, by crop. We then provide greater detail, drawn from ARMS, for the eight major field crops that account for over 70 percent of the acreage receiving manure. We also explore manure disposal among producers of manure—specifically, hog, dairy, and poultry operations.[9]

Manure Use in the Aggregate

Manure was spread as fertilizer on about 15.8 million acres of U.S. cropland in 2006, just 5 percent of total planted acreage of 315.8 million acres (Table 1).[10] In principle, manure could be spread on far more cropland, mitigating the risks that arise from excessive concentrations of manure and replacing high-priced commercial fertilizers. But there are several barriers to wider use.

Over half (52 percent) of harvested crop acres were on farms with no livestock production at all.[11] Across crops, the share of harvested acreage on farms with no livestock varied from 80 percent for cotton and 70 percent for peanuts, to 51-62 percent for soybeans, corn, wheat, sorghum, and barley, to

Table 1
Manure applications by crop, 2006

Commodity receiving manure	PII year	Manure share (%)	2006 Acres (000)		Share of all manured acres
			Planted	Manured	
Major Crops					
Barley	2003	2.9	3,452	100	0.6
Corn	2005	11.6	78,327	9,086	57.6
Cotton	2003	2.6	15,274	397	2.5
Oats	2005	9.0	4,168	375	2.4
Peanuts	2004	4.2	1,243	52	0.3
Sorghum	2003	0.7	6,522	46	0.3
Soybeans	2006	1.3	75,562	982	6.2
Wheat	2004	0.7	57,344	401	2.5
Subtotal		**4.7**	**241,892**	**11,439**	
Hay and Grasses					
Hog, dairy, broiler				3,360	
Beef				791	
Subtotal		**6.9**	**60,087**	**4,151**	26.3
All other crops		**1.4**	**13,856**	**194**	1.2
Total		**5.0**	**315,835**	**15,784**	**100.0**

Sources: Planted acreage estimates are drawn from USDA/NASS Acreage report released in June, 2006, while manured acreage estimates for major crops are based on data drawn from ARMS Phase II surveys, 2003 through 2006. Further explanation of the estimation procedures, and detail on estimation of hay and grass acreage, can be found in Text Box: Estimating the Amount of Cropland Receiving Manure.

[9]We use 2006 NASS survey data for estimates of planted acreage, in total and by commodity. All other data in this section are drawn from ARMS data.

[10]See box "Estimating the Amount of Cropland Receiving Manure" (p. 9), for details.

[11]Using 2006 ARMS Phase III data, which reports harvested acres.

less than 30 percent for oats and hay. Farms that combine crop and livestock production are much more likely to spread manure on their cropland.

The high cost of transporting manure limits its use on farms without livestock, and also limits its application to the distant fields operated by farms with livestock. Finally, the variation in nutrient loadings in manure may limit applications to some crops.

Among commodities, corn (9.1 million acres) accounts for over half of all acreage spread with manure. Corn is the country's largest single crop, with 24.8 percent of all planted acres in 2006. But corn's share of manured acreage is more than twice as large as its share of all planted acreage, largely because corn is demanding of nitrogen and is grown for feed on many dairy and hog operations. The other major manure recipients are hay and grasses, which account for 4.2 million acres, and soybeans, with 0.98 million acres.[12] Six other field crops (barley, cotton, oats, peanuts, sorghum, and wheat) together account for a total of 1.4 million acres.[13]

Manure is a more important nutrient source for some crops than for others. Nearly 12 percent of the acreage planted to corn received manure, as did 9 percent of oats and 7 percent of hay (Table 1). But other crops are much less intensive users—just over 4 percent of peanut acreage received manure, compared to 2.6 percent of cotton, 1.3 percent of soybeans, and less than 1 percent of sorghum and wheat.

While corn accounts for 79 percent of manured acreage among the eight major field crops, it accounts for 87 percent of the manure nitrogen applied (Figure 2). Nutrient application rates are higher for corn, wheat, and cotton than for other crops, with corn receiving 140 pounds of manure nitrogen per acre, on average, as well as 69 pounds of potassium and 91 pounds of phosphorus (Figure 1).[14]

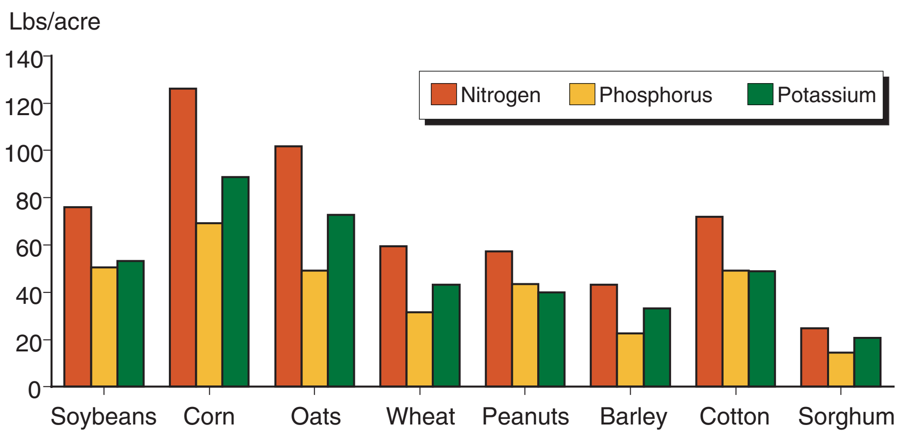
The share of acreage receiving manure has likely risen since 2006, and it may continue to rise. Changes in crop prices led to a sharp increase of planted corn acreage after 2006. In addition, commercial fertilizer prices rose sharply in 2006-08, which should have led to some substitution of manure

[12]Soybeans account for 24 percent of harvested acres but less than 7 percent of acres receiving manure, likely due to the crop's low nitrogen requirements.

[13]Manure that is applied to corn in one year may provide nutrients for another crop—such as soybeans—planted on the land in a following year. Our data are based only on the crop planted in the year the manure was applied.

[14]Application rates vary considerably across farms, due to differences in crop rotation, commercial fertilizer use, and soil characteristics. The differences in mean values reported in Figure 1 are not statistically significant.

Figure 1
Manure nutrient application rates, by crop



Source: ARMS Phase II, 2003-2006.

Estimating the Amount of Cropland Receiving Manure

In Table 1, we estimate the total number of cropland acres receiving manure in 2006. Since no one source provides an estimate of the total number of acres receiving manure in the U.S. in any given year, we relied on several different sources.

ARMS Phase II data provide estimates of planted acreage, and acreage receiving manure, for barley, corn, cotton, oats, peanuts, sorghum, soybeans, and wheat. Phase II data have two major weaknesses. First, the eight major field crops are surveyed in different years. We need to make some adjustments to estimate manured acreage for each crop in 2006. Second, the eight crops accounted for 77 percent of total planted acreage in 2006, and we must estimate manured acreage for the remaining cropland.

For the major field crops, we assume that each crop's ratio of manured to planted acreage remained constant over time. For example, 11.6 percent of corn acreage in the 2005 ARMS Phase II survey received manure, so we assume that 11.6 percent of 2006 acreage received manure. Similarly, 2.6 percent of cotton acreage in the 2003 survey received manure, so we assume that 2.6 percent of 2006 acreage received manure. Estimated 2006 manured acreage is the product of USDA/NASS estimates of 2006 planted acreage and each crop's manured acreage share (USDA, NASS, 2006).

The eight crops listed in the top panel of Table 1 accounted for 77 percent of total planted acreage in 2006. The major omitted crop is hay, with 60.1 million planted acres, according to NASS. Other omitted crops accounted for 94 percent of the remaining 13.9 million acres: Rice (2.9), sunflowers (1.9), edible beans (1.5), rye (1.4), sugarbeets (1.4), canola (1.0), sugarcane (0.9), flaxseed (0.7) millet (0.6), and tobacco (0.3).

We have no ARMS Phase II surveys of hay and grasses, but ARMS Phase III surveys covered hog, dairy, and broiler producers in 2004, 2005, and 2006, respectively. Each questionnaire contained questions on the application of manure from those operations to hay and grasses.

Respondents to the dairy survey were asked directly for the amount of hay acreage spread with manure—1.93 million acres. Broiler and hog producers were asked to list the major crop receiving manure, the amount of major crop acreage that received manure, and the total acreage that received manure. For broiler growers, those who listed hay and grasses as the primary crop, spread manure on 685,000 acres of hay and grasses. But those who listed another primary crop spread manure on 63,000 acres in addition to the primary crop. If all of those acres were hay and grassland, then total hay and grassland acreage receiving manure could have been as high as 748,000 acres.

Following the same rationale, we estimate that hog producers spread manure on 244,000-516,000 acres of hay and grassland. Those who listed hay and grasses as the primary crop spread manure on 244,000 acres. Those who listed another primary crop spread manure on 2.21 million acres of the primary crop (90 percent was corn) and 272,000 acres of secondary crops. If all of those secondary acres were hay and grasses, then manured hay and grass acreage could have been as high as 516,000 acres.

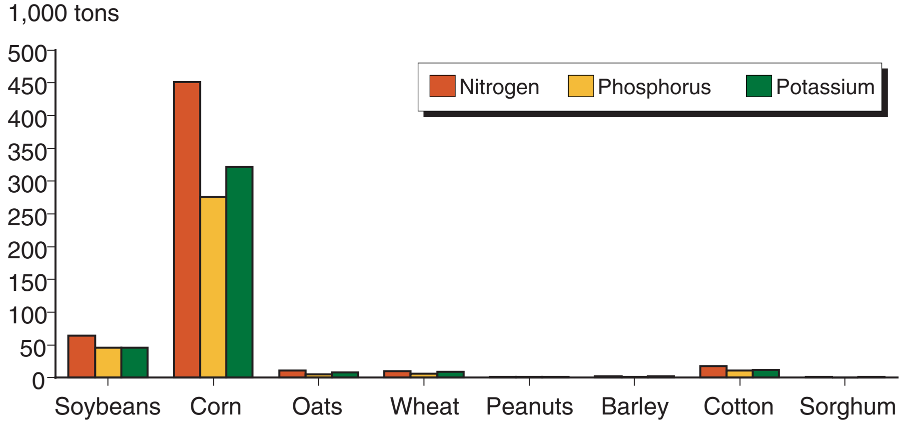
Taken together, hog, broiler, and dairy producers spread manure on between 2.86 and 3.20 million acres of hay and grassland. However, the ARMS commodity versions cover only producers in States amounting to 90 percent of production. Assuming that producers in other States act like producers in major States, we should increase our estimates by 11 percent, to a range of 3.17-3.55 million acres. We report the midpoint, 3.36 million acres, in Table 1.

Beef manure, primarily from feedlots, can also be spread on hay and grasses, but we have no ARMS surveys of feedlot manure management practices. We can, however, use the Phase II surveys to estimate the number of acres of the eight major field crops that received manure from animals of different types—beef cattle, dairy cattle, horses, hogs, sheep, and poultry. We estimate that the amount of hay and grass acreage receiving dairy, hog, or poultry manure was 24.8 percent of the major crop acreage receiving that manure. If we assume that beef manure was spread in the same proportion, then we can estimate that 791,000 acres of hay and grasses received beef cattle manure in 2006 (Table 1). Adding the beef estimate to the stronger estimates for dairy, hogs, and broilers, we can raise our estimate of hay/grass acreage receiving manure to 4.15 million acres from 3.36 million acres.

Finally, we need to estimate the number of acres of other field crops receiving manure. Other field crops accounted for 13.9 million planted acres in total. We assumed that acreage planted to those crops received manure in the same proportions as the major field crops, with corn excluded. Under that assumption, 1.4 percent of the acreage planted to those crops, or 194,000 acres, received manure in 2006. We exclude corn because it is grown in close proximity to livestock operations and because of its high nitrogen requirements; including corn in the calculation would raise the estimate to 765,000 acres. In total, we estimate that 15.784 million acres received manure in 2006.

Figure 2

Total tons of manure nutrients applied, by crop



Source: ARMS Phase II, 2003-2006.

for commercial fertilizers. Corn uses more nutrients and relies on animal manure to a greater extent than other crops. Finally, large livestock producers are coming under increasing regulatory pressure to remove manure that is in excess of agronomic needs from their operations, and removal is usually to other cropland off the operation.

Which Farmers Use Manure?

Geography, commodity choices, and agronomic requirements create strong links between various crops and specific livestock species (Table 2). For example, dairy manure is used by more than half of the corn, oats, and barley operations who use manure (Figure 3). Beef manure was used by more than half of the sorghum and wheat operations that used manure, while poultry litter was used by more than half of the peanut and cotton operations that used manure. Only soybeans received manure from a wide variety of species. The linkages tend to follow from the proximity of specific crops to areas of livestock production.

Table 2

Acreage receiving manure, by crop and species, 2006

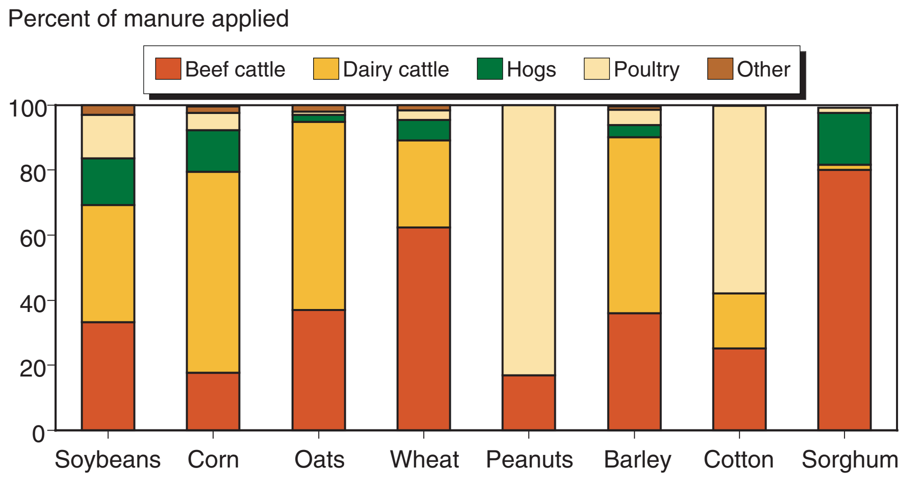
Crop	Acres applied (000), by source of manure					
	Dairy cows	Beef cattle	Swine	Poultry	Other	**All**
Barley	54	36	4	4	2	**100**
Corn	5,612	1,617	1,161	472	224	**9,086**
Cotton	67	101	0	228	1	**397**
Oats	218	139	8	3	7	**375**
Peanuts	0	8	0	44	0	**52**
Sorghum	1	37	7	1	0	**46**
Soybeans	354	327	139	132	30	**982**
Wheat	107	250	26	12	6	**401**
All	**6,413**	**2,515**	**1,345**	**896**	**270**	**11,439**

Note: other sources include equine, sheep, and biosolids.

Source: ARMS Phase II surveys for the specific crops, 2003 through 2006, adjusted to a 2006 planted acreage base using the June 2006 USDA/NASS Acreage report.

Figure 3

Animal source of manure, by crop



Source: ARMS Phase II, 2003-2006.

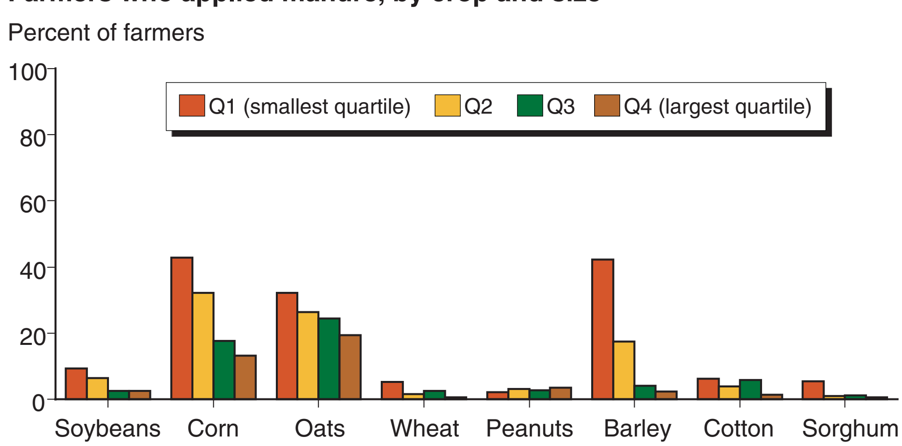
Most crop enterprises cover a wide range of planted acreages, from 10 acres up to several thousand planted to a single crop. Smaller enterprises are more likely to use manure in most crop categories (Figure 4). We sorted producers of each of the eight field crops into four size classes, depending on their planted acreage of the commodity, and calculated the proportion of producers in each size class who use manure.[15] Among corn farms, 43 percent of operations in the smallest quartile used manure, compared to only 14 percent in the largest quartile. The pattern—of a higher incidence of manure use among smaller crop enterprises—holds for most other crops as well. Only in peanuts is there no clear relation between planted acreage and manure use.

The pattern likely reflects the overall mix of commodities produced by the farm—that is, large field crop operations are more likely to specialize in field crop production, with no livestock enterprises, and as a result find manure fertilizer to be more costly for them, when transport costs are considered. In ARMS Phase III data, which provides information on all commodities produced by the farm, farms with no livestock tend to have higher planted crop acreages than farms with livestock. For example, the mean 2006 corn

[15]Specifically, the classes are quartiles, with Q1 representing the smallest 25 percent of crop acreages, Q4 representing the largest 25 percent, and Q2 and Q3 capturing the 26th-50th and 51st-75th percentiles, respectively..

Figure 4

Farmers who applied manure, by crop and size



Source: ARMS Phase II, 2003-2006.

acreage among farms with corn but no livestock was 272 acres, substantially higher than the 203 acres planted by farms with corn and livestock.

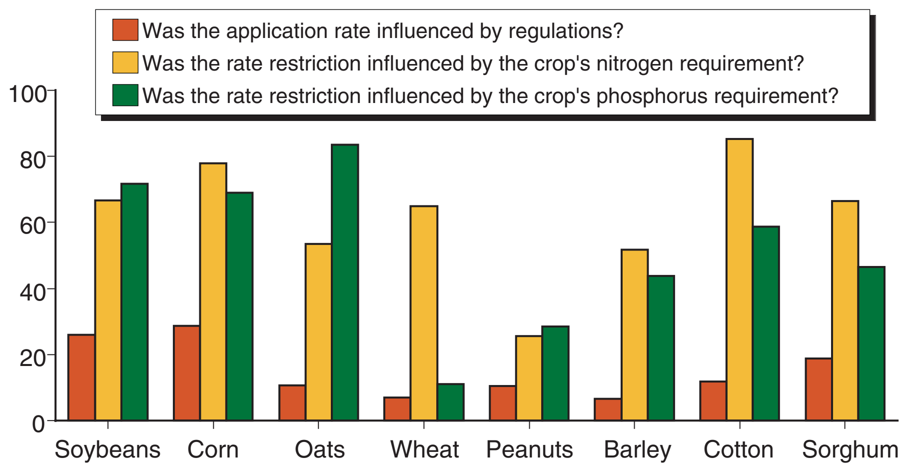
Regulations can impact manure use as well. Regulations influenced manure application rates on 29 percent of the corn acres receiving manure, along with 26 percent of the soybean acres, 19 percent of sorghum acres, and 7-11 percent of the other crops (Figure 5).[18] Regulations may be based on the crop's nitrogen or phosphorus requirements. Among producers whose application rates were influenced by regulations, nitrogen requirements were cited as a limiting factor by 80 percent of corn producers, 70 percent of soybean producers, and 90 percent of cotton producers. Phosphorus requirements played a major role for corn, oats, soybean, and sorghum producers. However, regulations influenced manure use much more on planted corn and soybean acres than for other crops (Figure 6).

[18]About 7 percent of the corn farms that are affected by restrictions, and 27 percent of the soybean operations, produce no livestock. Farms that produce only crops, and that use manure obtained from livestock operations, are not required to obtain permits for the discharge of manure nutrients under the Federal Clean Water Act. These farms are likely influenced by State and local restrictions.

Figure 5

Manure applications influenced by national, State, or local regulations

Percent of manured acres

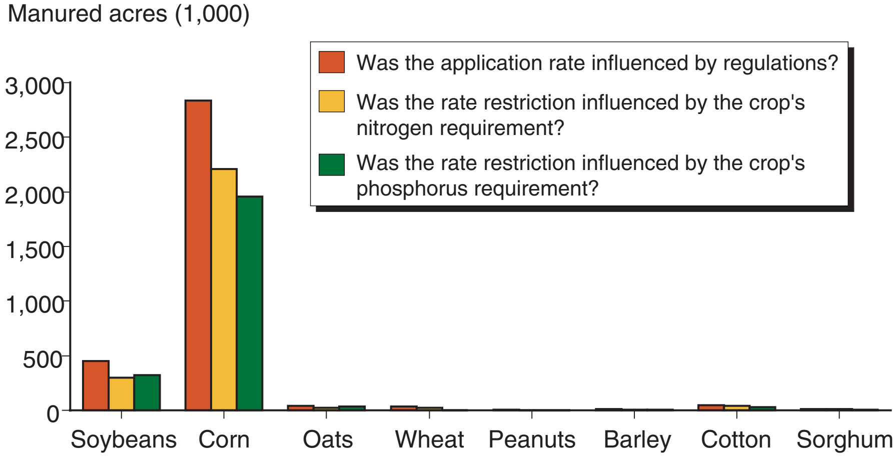


Source: ARMS Phase II, 2003-2006.

Figure 6

Manure applications influenced by national, State, or local regulations

Manured acres (1,000)



Source: ARMS Phase II, 2003-2006.

Manure Transport Among Farms

Most operators apply the manure produced on the farm to the farm's cropland (Figure 7). Among farmers who use manure, more than 80 percent of barley, corn, oats, soybean, and wheat producers, and 71 percent of sorghum producers, apply manure produced on-farm. The exceptions occur in peanuts and cotton, where most manure is acquired from other farms—recall that peanut and cotton farms tend to rely on poultry litter, which is dry and hence less costly to transport and is produced on farms that often have no crop enterprises.

Many farmers acquire manure for no explicit cost (they may pay to transport it). Some pay for the manure, and, in some places, livestock producers pay farmers to accept manure. Peanut and cotton operations purchase most of the manure that they acquire off-farm, as do most sorghum producers, but corn and soybean producers, who, because of their size, still account for most of the manure that is acquired, are more likely to obtain manure for no cost than to pay for it (Figure 7).

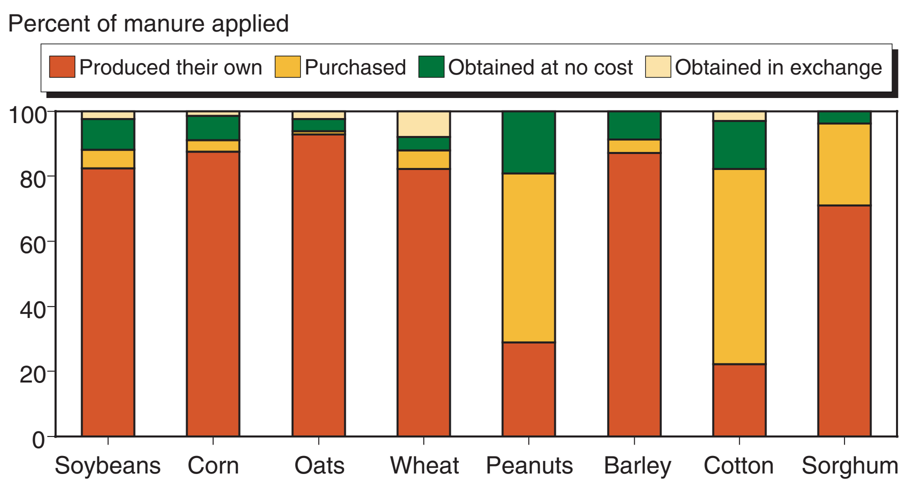
We used ARMS Phase III dairy, hog, and broiler surveys to look at manure removal from livestock operations (Table 3). Only 5 percent of dairy farms remove any manure from the farm, but 19 percent of all manure is removed. This is because larger farms are far more likely to remove manure, and farms in the largest class (2,000 animal units, about 1,500 cows) remove nearly half of their manure.

A similar pattern holds among hog operations. Only 16 percent of farms remove manure, but 26 percent of all manure is removed, and the share that is removed increases in larger operations. The largest operations (at least 1,000 animal units, or 6,000-7,000 market hogs removed in a year) remove one-third of all the manure generated on the farm.

Broiler operations are different, because many have no cropland and because broiler litter is less costly to transport. Sixty-one percent of broiler litter is

Figure 7

Manure acquisition method, by crop



Source: ARMS Phase II, 2003-2006.

Table 3

Manure removal on dairy, hog, and broiler operations, by size of farm

Commodity and size class	Percent with no cropland	Manure removed (percent)
Dairy		
Farms	5	5
Weighted by production	12	19
By size class (AU)		
<300	3	3
300-649	12	12
650-999	12	23
1,000-1,999	22	37
2,000 or more	26	49
Hogs (market)		
Farms	10	16
Weighted by production	19	26
By size class (AU)		
<300	7	13
300-649	10	20
650-999	14	29
1,000 or more	27	33
Broilers		
Farms	32	58
Weighted by production	29	61
By size class (AU)		
<300	33	56
300-649	30	63
650-999	28	63
1,000 or more	9	68

Notes: One animal unit equals 1,000 pounds (liveweight) of livestock or poultry in inventory. Average liveweight of animals in inventory was assumed to be 1,350 pounds for cows and bulls; 375 pounds for breeding swine; for slaughter swine, one-half of the difference between market weight and weight when entering the farm's inventory; and half of the average weight at removal for broilers.

Source: ARMS Phase III data, reported in MacDonald and McBride (2009)

removed from the operation. Even the smallest classes remove most, but the largest remove close to 70 percent.

Manure markets tend to be highly localized. In some areas, manure carries enough value as fertilizer that crop producers are willing to pay to receive it; in other areas, livestock producers must pay other farmers to take the manure. About 20 percent of the dairy and hog manure that is removed from farms is sold, as is 36 percent of broiler litter.[17] About 60 percent of the hog and broiler manure that is removed from farms is given away for no exchange of money. Prices for manure are determined by the quantities produced in an area relative to the amount of nearby cropland, the mix of crops grown, and the cost of transporting manure. With production shifting to large livestock operations, which are coming under increasing pressure to reduce nutrient applications to their own land, we can expect to see increased manure removals.

[17]See table 4, where about 20 percent of removed dairy and hog manure is sold, and about 36 percent of removed broiler litter is sold.

Table 4

Manure removal transactions from livestock operations

	Dairy	Hogs	Broiler
	Percent of total production		
Manure removed from operation	19	26	61
Sold by operation	4	5	22
Operation paid to haul it away	7	3	3
Operation gave it away	8	18	36
Prices	*$ per cwt of production*		
Revenue from manure sales	0.28	0.22	0.20
Expenses to haul manure away	0.39	0.34	0.31

Source: Authors' calculations, based on data from the Agricultural Resource Management Survey, Phase III, version 4, 2004 (hogs), 2005 (dairy), and 2006 (broilers).

Substitution Between Manure and Commercial Nitrogen Applications

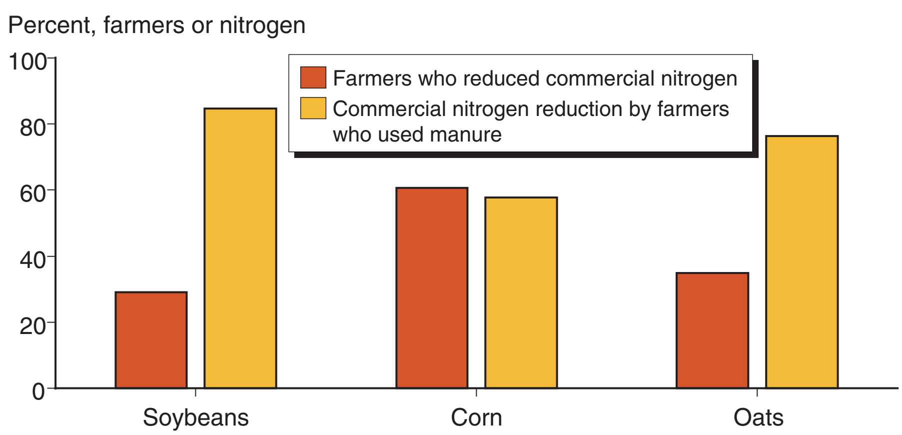
Very few farms rely exclusively on manure as a source of fertilizer because manure may not have the right combination of nutrients for the crop and because some fields may be at a considerable distance from manure storage facilities. Increased use of manure may allow farmers to reduce, rather than eliminate, their commercial fertilizer applications.

Three ARMS Phase II surveys (corn, oats, and soybeans) asked farmers whether their use of manure allowed them to reduce commercial nitrogen applications. The three crops accounted for 91 percent of manured acreage among the eight major field crops, and they each have different agronomic requirements for nutrients; corn has among the highest nitrogen requirements while soybeans have among the lowest.

Manure clearly substitutes for commercial fertilizers in corn production—61 percent of corn farmers reported that they reduced commercial nitrogen applications on their fields that received manure, and those operators cut their commercial nitrogen applications by 58 percent, on average (Figure 8). Farmers who applied commercial and manure fertilizers in 2005 had

Figure 8

Substitution between manure and commercial nitrogen



Source: ARMS Phase II, 2003-2006.

commercial fertilizer costs that were $17.60 an acre (37 percent) lower than farmers who used only commercial fertilizers on corn.

Substitution is weaker for oats and soybeans; 35 percent of oats and 29 percent of soybean producers who applied manure said that manure applications allowed them to reduce commercial nitrogen applications, although those farmers that did so cut their commercial nitrogen applications substantially—by 76 percent (oats) and 85 percent (soybeans). Those respondents who did not reduce commercial nitrogen applications were not necessarily applying manure and commercial nitrogen to their field; they may have not intended to apply any commercial fertilizers, and so had no applications to reduce.

Methods of Manure Application

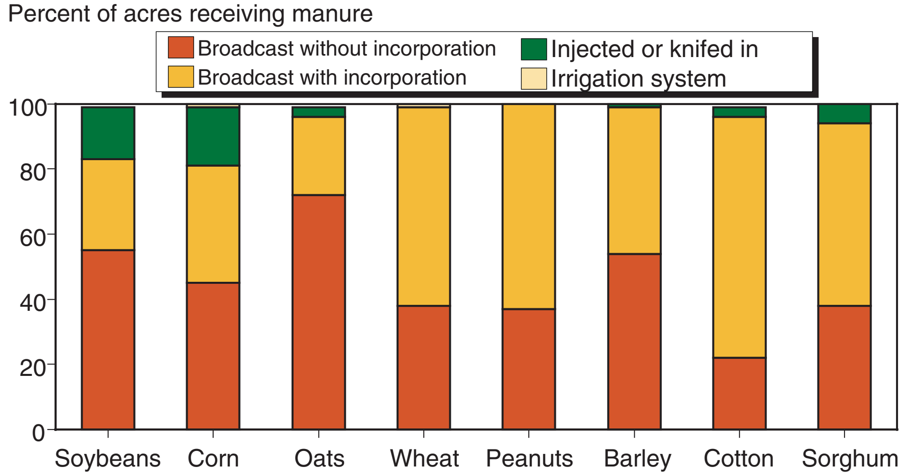
Farmers can apply manure in several ways. ARMS Phase II surveys specify four. It can be broadcast, or spread on top of the soil. It can be broadcast and then incorporated into the soil by tillage shortly after the initial application. It can be injected into the soil during application. Finally, it can be sprayed onto the soil through an irrigation system. Broadcasting may save on some costs, but it may also encourage run-off of nutrients and may lead to more odor problems.

Most farmers either broadcast their manure, or broadcast with incorporation, and the incidence of each method varies with the crop (Figure 9). Farmers are far more likely to broadcast without incorporation on corn, soybeans, and oats, while manure is usually broadcast with incorporation on cotton, sorghum, peanut, and wheat fields.

Injection and irrigation systems require significant new capital investments, and relatively few farmers in any commodity use them, although the former method does cover significant shares of corn and soybean acreage (Figure 10). Only about 10 percent of corn operators who apply manure report that they inject or knife manure into the soil, but the method covers 18 percent of manured corn acres. Similarly, 25 percent of corn operations that use manure choose to broadcast with incorporation, and those operations cover 36 percent of manured corn acres.

Figure 9

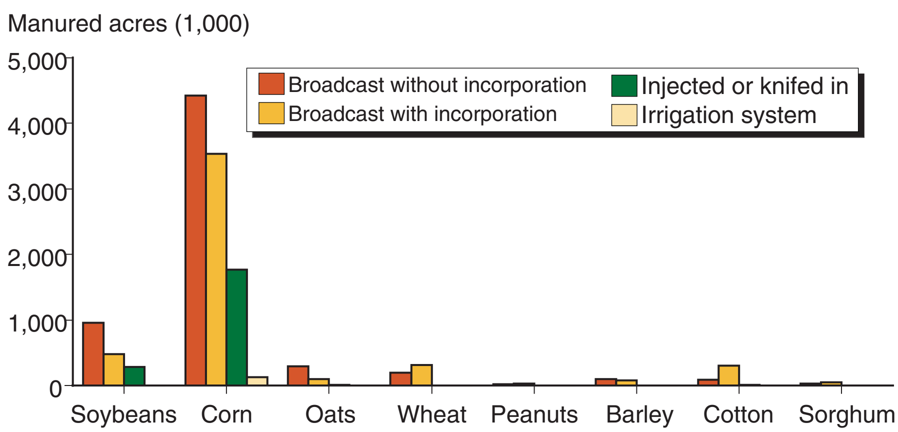
Method of manure application, by crop



Source: ARMS Phase II, 2003-2006.

Figure 10

Manure application method, by crop



Source: ARMS Phase II, 2003-2006.

Impacts on Animal Operations of Restricting Manure Applications

Large livestock operations produce very large quantities of manure nutrients, often well in excess of nutrient requirements for the crops grown on the farm (Gollehon et al., 2001). Excess nutrients can create environmental risks, and manure management practices are coming under increased scrutiny in the regulatory and legal arenas.

Certain large "concentrated animal feeding operations" (CAFOs) are required to have a pollution discharge permit under the Clean Water Act, and those operations must implement a nutrient management plan (NMP) as part of their National Pollution Discharge System (NPDES) permit. CAFOs not required to obtain a discharge permit must implement a NMP if they wish to claim the stormwater exemption contained in the Clean Water Act. By 2004-2006, 62 percent of U.S. hogs, 60 percent of broilers, and 49 percent of dairy cows were on operations that had NMPs.[18]

An NMP requires that manure nutrients be applied at agronomic rates. If operations had been overapplying manure, then they have several options for complying with NMP requirements. They may adjust feeding regimens to reduce the amount of nutrients in a given amount of manure, thereby reducing manure and nutrient production per finished animal. They may acquire more land for spreading manure, either by expanding their own crop production or by persuading neighboring farmers to take their manure. Manure can also be dried and used as feedstock for energy production or separated into dry and liquid components. Dried manure that retains nutrients can be bagged and sold as garden fertilizer, or it can be shipped greater distances for field crop application.

How individual farms adjust to application restrictions depends on several factors, including the number of animals on the farm, amount of land available on the farm for spreading manure, availability of land off the farm, willingness of neighboring cropland operators to accept manure, type of crops grown, and the type of nutrient standard the farm must meet (nitrogen or phosphorus).

ERS evaluated the costs of such requirements to the hog and dairy sectors in 2003 (Ribaudo et al., 2003). The study combined census of agriculture data on livestock inventories for each U.S. county with ASAE estimates of manure production by species to generate estimates of aggregate farm and county-level manure production.[19] The findings of this analysis can be used to draw inferences for how the rules embodied in NMPs would affect all animal feeding operations, not just those regulated by EPA. The results of this analysis are summarized here.

Hogs

Ribaudo et al. (2003) used the 1998 hog ARMS to estimate the amount of additional land each farm would need to meet nitrogen (N) and phosphorus (P) based standards, and the cost of meeting a nutrient management plan. They accounted for the different manure storage technologies used by

[18]In 2004 (hogs), 2005 (dairy), and 2006 (broilers). Correspondingly, 30 percent of hog farms, 32 percent of dairy farms, and 60 percent of broiler farms had an NMP. Plans cover more animals than farms because larger farms are more likely to be required to have one.

[19]The Ribaudo et al. estimates are based on older 1988 ASAE standards, and have not been updated to reflect the 2005 revision of the standards.

hog operations, which affect both the nutrient content and the weight of the material that must be moved and applied. For example, operations in the Southeast tend to use lagoons, which greatly dilute manure, and apply waste to fields with irrigation sprinklers. Operations in the Midwest tend to use slurry tanks or pits and to apply manure with mobile equipment. The cost of implementing a nutrient management plan has three components: recordkeeping and testing, application, and transportation. All three were accounted for in the analysis.

In 1998, the hog sector was dominated by four types of operations—farrow-to-finish (50 percent), feeder pig-to-finish (31 percent), farrow-to-feeder pig, and weanling-to-feeder pig operations. Most hog farms (85 percent) contained less than 300 animal units (defined as 1,000 lbs of live weight). Twelve percent contained between 300 and 1,000 animal units, and only 3 percent were large, with at least 1,000 animal units. When looking at production, however, large operations produced 34 percent of all hogs (Table 5). It is these operations that were the focus of EPA's 2003 regulations.

Farm size plays a major role in whether an animal feeding operation is defined as a CAFO and regulated by EPA. EPA defines size for the purpose of Clean Water Act implementation on the basis of Animal Units (AU) different from USDA's definition of animal units (live weight). EPA defined an animal unit as 2.5 swine weighing more than 25 kg. Those operations with more than 1,000 AU were classified as large and generally made up the bulk of operations that needed a discharge permit from EPA.

In the Ribaudo et al. analysis, operations were classified into three size classes: large (>1,000 AU), medium (between 300 and 1,000 AU), and small (less than 300 AU). Operations with less than 27 animals were dropped from the analysis, on the assumption that these are not confined animal feeding operations. Also, the EPA size definitions did not account for hogs weighing less than 25 kg, so those operations containing only pigs smaller than 25 kg (wean to feeder) were dropped from the analysis.

For each farm in the sample, the acreage needed to apply manure at agronomic rates was compared with the acreage reported as receiving manure and with the total acreage operated by the farm deemed suitable for receiving manure. Farms not meeting the standard were assumed to spread on a larger area, which may have necessitated moving manure off the farm to cropland and pasture operated by other farmers. Ribaudo et al. examined the impact of the standard for all three size classes across five regions.

Table 5
Characteristics of hog producers, by size class, 1998

Item	<300 units	300-1,000 units	>1,000 units
Number of hog farms	52,718	7,153	2,100
Percent of farms	85	12	3
Percent of sales	30	33	37
Percent of production	33	33	34

A unit represents 1,000 lbs of live weight.

Source: 1998 hog ARMS

On average, small farms were spreading on enough land to meet a nitrogen standard and would not be much affected by a requirement to meet an agronomic rate, although this varied by region (Table 6). Medium farms would need, on average, to increase the amount of land receiving manure by 33 percent. Large farms had the greatest need to spread on more land. On average, the amount of land needed for spreading would have had to increase by 114 percent. In addition, a phosphorus-based standard would greatly increase the amount of land required for spreading manure. Large farms would need, on average, about 1,000 acres of additional land for spreading.

The cost of meeting the application limit depends heavily on whether a farm has enough of its own land, or whether it must transport manure off the farm. If moved off the farm, the willingness of nearby crop producers to use manure is a major factor in how far manure must be hauled. Data on willingness-to-accept manure (WTAM) was lacking when the study was conducted, so the authors looked at a range, from 20 to 80 percent. As seen from Figure 11, per-AU costs are negative for medium and large farms and in most regions when willingness to accept manure exceeds 20 percent (because manure then has value, and producers obtain revenue for it). The

Table 6
Percentage of hog farms meeting N-based and P-based standards, by region and EPA size class, 1998

Region	Farms with confined hogs	Farms meeting N-based standard	Farms meeting P-based standard	Farms with adequate land for N-based standard	Farms with adequate land for P-based standard
	Number		*Percent*		
Eastern Corn Belt					
<300 AU	5,891	44.5	16.4	85.1	66.7
300 – 1,000 AU	2,658	34.8	7.3	84.4	59.0
>1,000 AU	1,110	20.1	0	56.1	25.1
Western Corn Belt					
<300 AU	10,903	50.1	11.8	92.1	72.1
300 – 1,000 AU	7,744	37.9	9.9	82.0	48.9
>1,000 AU	2,025	26.9	8.8	66.5	31.0
Mid-Atlantic					
<300 AU	423	15.4	1.1	54.9	46.9
300 – 1,000 AU	582	14.1	0	23.0	10.8
>1,000 AU	1,214	4.5	0	17.3	2.4
South					
<300 AU	1,236	32.5	11.2	81.7	68.6
300 – 1,000 AU	488	21.7	0.6	67.3	43.8
>1,000 AU	177	13.3	7.9	32.0	16.6
West					
<300 AU	393	19.2	7.6	28.2	25.4
300 – 1,000 AU	108	0	0	0	0
>1,000 AU	174	0	0	29.4	0
Nation					
<300 AU	18,846	45.8	12.8	87.1	68.7
300 – 1,000 AU	11,580	35.0	8.3	78.2	48.7
>1,000 AU	4,700	18.0	4.1	48.8	20.6

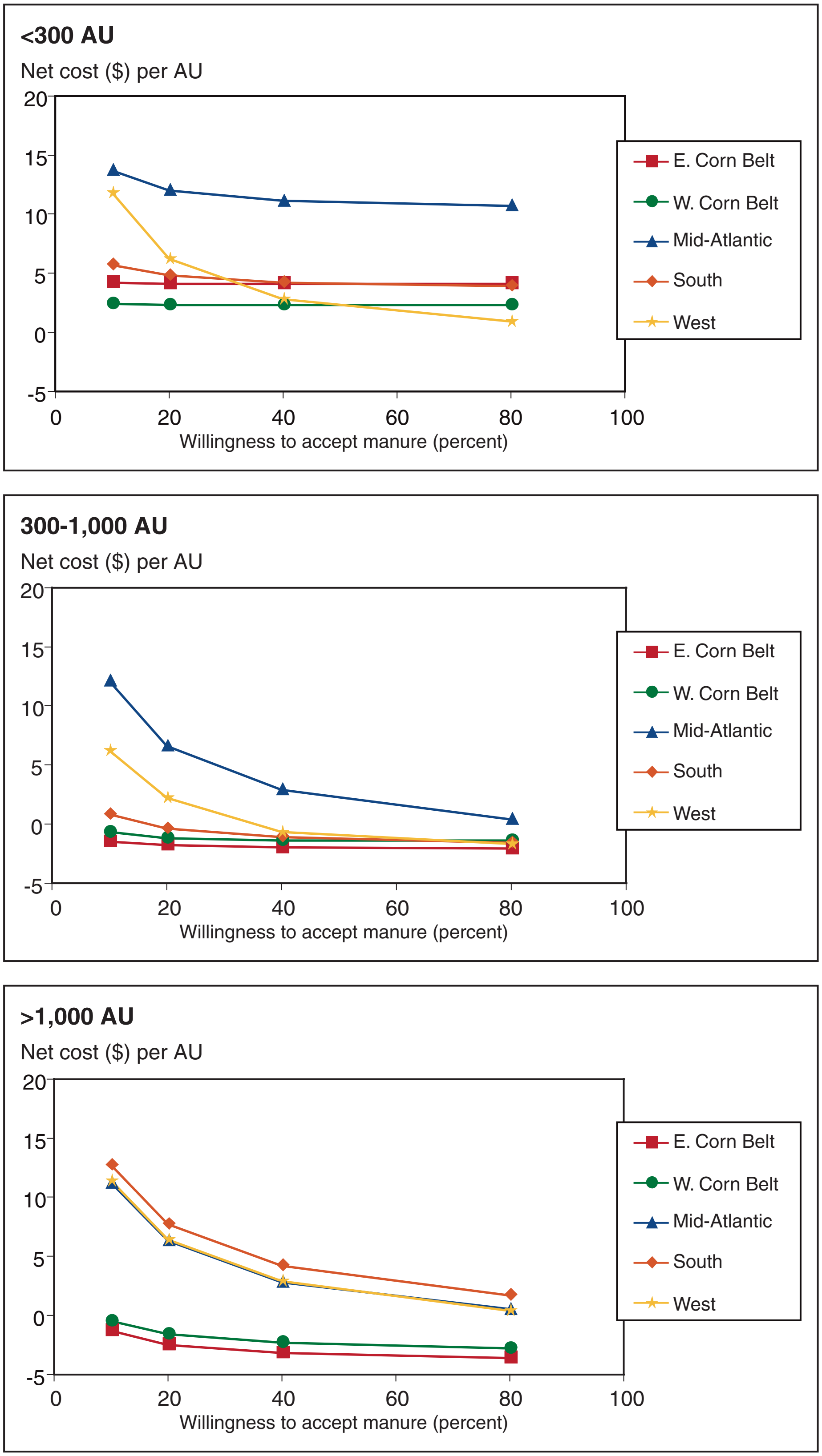
AU = 2.5 hogs of more than 25 kg.

Operations with fewer than 27 hogs, or containing only hogs weighing less than 25 kg, were dropped from the analysis.

Source: Ribaudo et al. (2003)

Figure 11

Average net cost of applying manure from hog farms following a nitrogen standard, by region



Source: Ribaudo et al., 2003.

Table 7

Average acreage being used for spreading and average acreage needed to meet nutrient standard on hog farms, by region and EPA size, 1998

Region	Manure volume	Acres being used	Acres on the farm[1]	Acres needed		
				N-based standard	P-based standard, baseline phytase	P-based standard, all phytase
Eastern Corn Belt	1,000 gal			*Acres*		
<300 AU	382	66.6	365.2	53.8	193.9	140.1
300 – 1,000 AU	1,027	110.7	705.2	145.0	466.6	352.4
>1,000 AU	4,081	179.6	756.7	349.0	1,143.5	863.7
Western Corn Belt						
<300 AU	514	75.9	451.4	61.6	229.2	161.9
300 – 1,000 AU	1,492	119.4	535.5	147.4	493.2	355.2
>1,000 AU	5,204	262.8	789.5	368.7	1,206.8	882.0
Mid-Atlantic						
<300 AU	1,053	16.1	144.0	57.6	172.3	135.5
300 – 1,000 AU	3,800	39.2	134.5	151.7	331.1	242.7
>1,000 AU	12,141	68.7	247.3	397.9	1,166.0	851.5
South						
<300 AU	998	39.5	342.3	49.8	115.3	82.2
300 – 1,000 AU	2,591	57.6	688.2	127.7	366.4	266.0
>1,000 AU	8,067	139.7	276.7	578.8	833.1	693.3
West						
<300 AU	1,646	40.7	163.0	127.5	170.7	120.2
300 – 1,000 AU	3,558	59.2	5.7	138.6	272.3	218.9
>1,000 AU	17,946	139.4	258.6	736.6	1,992.6	1395.2
Nation						
<300 AU	539	68.5	404.5	59.6	208.2	148.4
300 – 1,000 AU	1,562	110.2	556.9	146.2	471.5	344.0
>1,000 AU	7,302	184.2	603.5	393.6	1,196.9	882.1

[1]Acres owned or leased suitable for receiving manure.

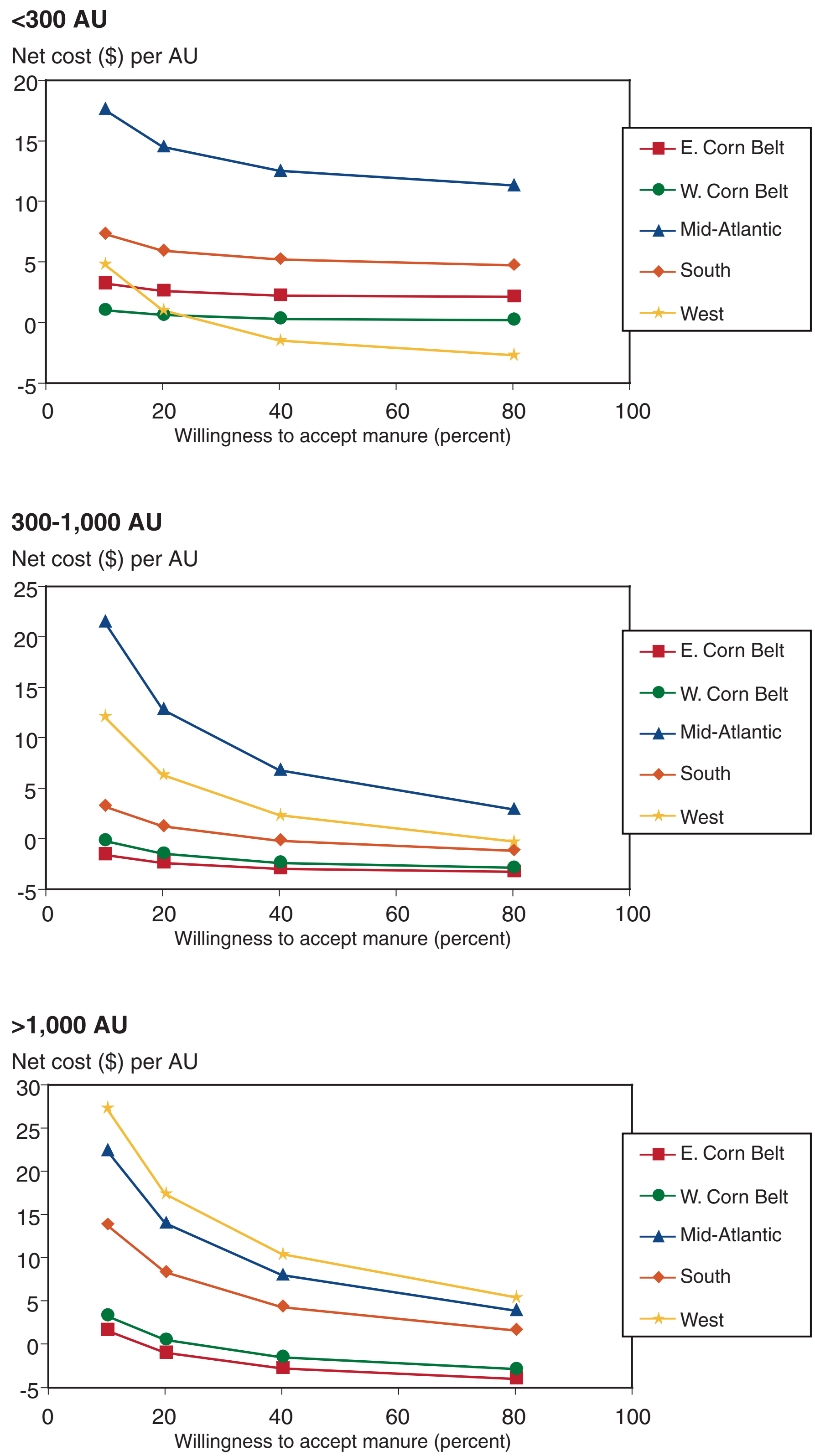
Source: Ribaudo et al. (2003)

Mid-Atlantic and West regions showed higher costs, primarily because of the relative scarcity of cropland suitable for receiving manure (manure must be transported farther). Among farms affected by a standard, small farms tend to have higher unit costs of meeting a standard. Costs are generally higher for P-based plans, but again, become negative for medium and large operations when willingness to accept exceeds 20 percent, in most regions (Figure 12).

To put these costs in context, they can be compared to production costs (operating costs plus allocated overhead). Data from ARMS indicated that hog production costs ranged from $360 to nearly $1,000 per animal unit for 1998, depending on the region, size of operation, and type of operation. At a high WTAM (80 percent), production costs would increase 1 percent or less across all regions and all size classes, for meeting either an N- or P-based standard.

At lower WTAM, impacts on production costs are noticeably higher for large operations than for small and medium operations in some regions. Under an N-based standard with a WTAM of 20 percent, the impact on production costs for large operations in the Corn Belt are negligible and slightly higher

Figure 12
Average net cost of spreading manure from hog farms following a phosphorus standard, baseline phytase use, by region



Source: Ribaudo et al., 2003.

for medium and small operations (Figure 13). In the other regions, production costs increase from 1 to 2 percent for large operations. For a P-based standard, the increases in costs for regions other than the Corn Belt are larger, ranging from 2 to 3.5 percent for large operations.

Animal diet modification is one approach for reducing nitrogen and phosphorus content of excreted manure. The phosphorus content of hog manure can be reduced by using reformulated feed containing the enzyme phytase. Phytase enables hogs to better utilize phosphorus in grain, thus reducing the need to add dicalcium phosphate or other inorganic phosphorus additives common in hog feed mixes. The addition of phytase to feed can reduce the P content of manure by up to 45 percent and, because phytase replaces dicalcium phosphate in hog diets, usage may also reduce feed costs.

This reduction is seen in the study results. The amount of land needed by farms having to spread manure is reduced by about 27 percent for all size classes. Large operations would benefit most if phytase were used in feed, as hauling costs make up a larger share of the costs of meeting a P-based standard (Figure 14).

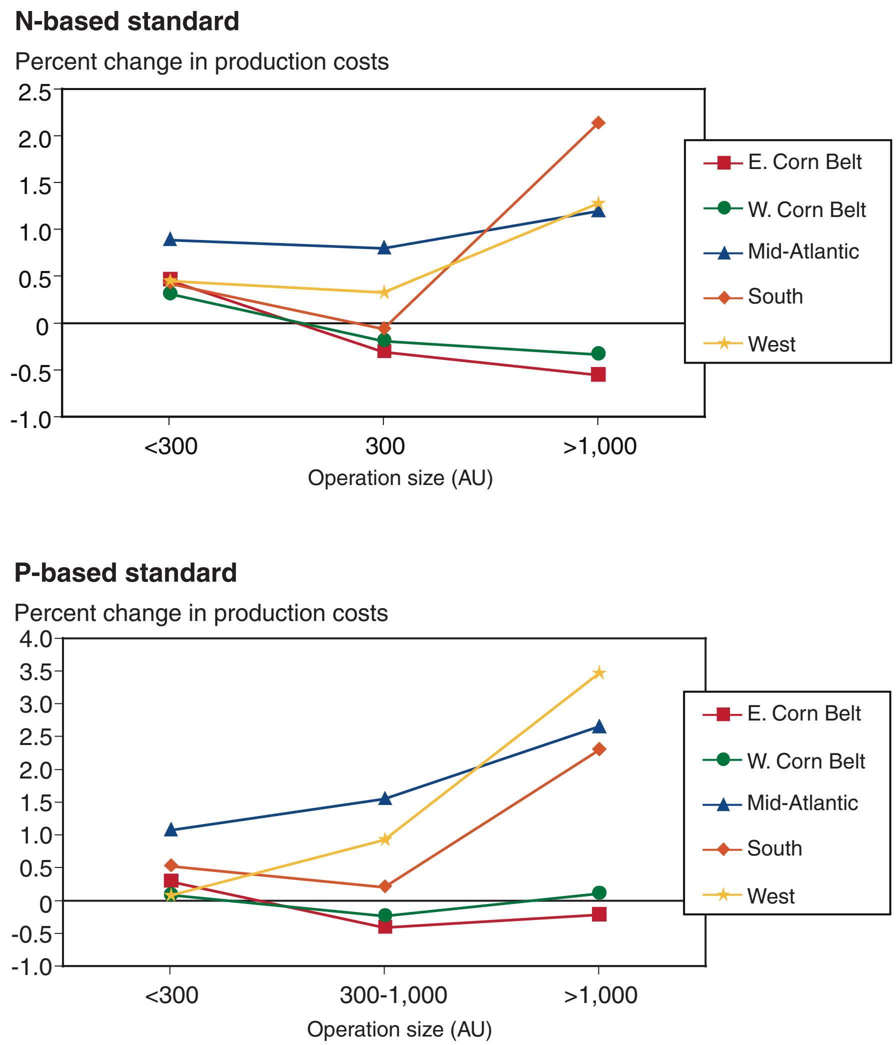
The hog sector changed measurably in the decade after 1998. We looked at how those changes might alter the Ribaudo et al. findings, by comparing data from 1998 with data from the 2004 ARMS hog version. The number of small farms fell greatly, while the number of medium and large operations increased—large hog operations with at least 1,000 AUs accounted for 46 percent of production in 2004, up from 34 percent in 1998.

Perhaps in response to public pressure to reduce environmental impacts, larger operations more often removed manure from the farm, added microbial phytase to hog feed, and followed a comprehensive nutrient management plan (Key, McBride, and Ribaudo, 2009). Whereas 23 percent of hog manure was removed from farms in 1998, farms removed 31 percent of all hog manure in 2004. With more manure removed, and with manure application intensities (animal units per acre) on large farms dropping by 15 percent, overall application intensities did not change between 1998 and 2004, even though production shifted to larger farms. Farmers also took steps to alter the nutrients in manure; in 1998, 4 percent of hog producers, accounting for 12 percent of production, added phytase to their feed. By 2004, 13 percent of producers, accounting for 30 percent of production, were doing so. These steps make it easier for large farms to meet a nutrient application standard, thus reducing the added cost of meeting a standard. Similar changes were not observed for small and medium sized operations. Application intensity increased for small and medium sized operations, implying that the costs of meeting a nutrient standard may be higher among smaller operations than in 1998.

Dairy

Ribaudo et al. (2003) also analyzed the impacts a nutrient application standard would have on dairies, using data from the 2000 dairy ARMS survey. As with hogs, the dairy sector has many small operations. In 2000, 92 percent of all dairies had fewer than 200 head. Less than 1 percent of operations had 1,000 or more cows, but they contained over 19 percent of the sector's cow inventory and accounted for 23 percent of production.

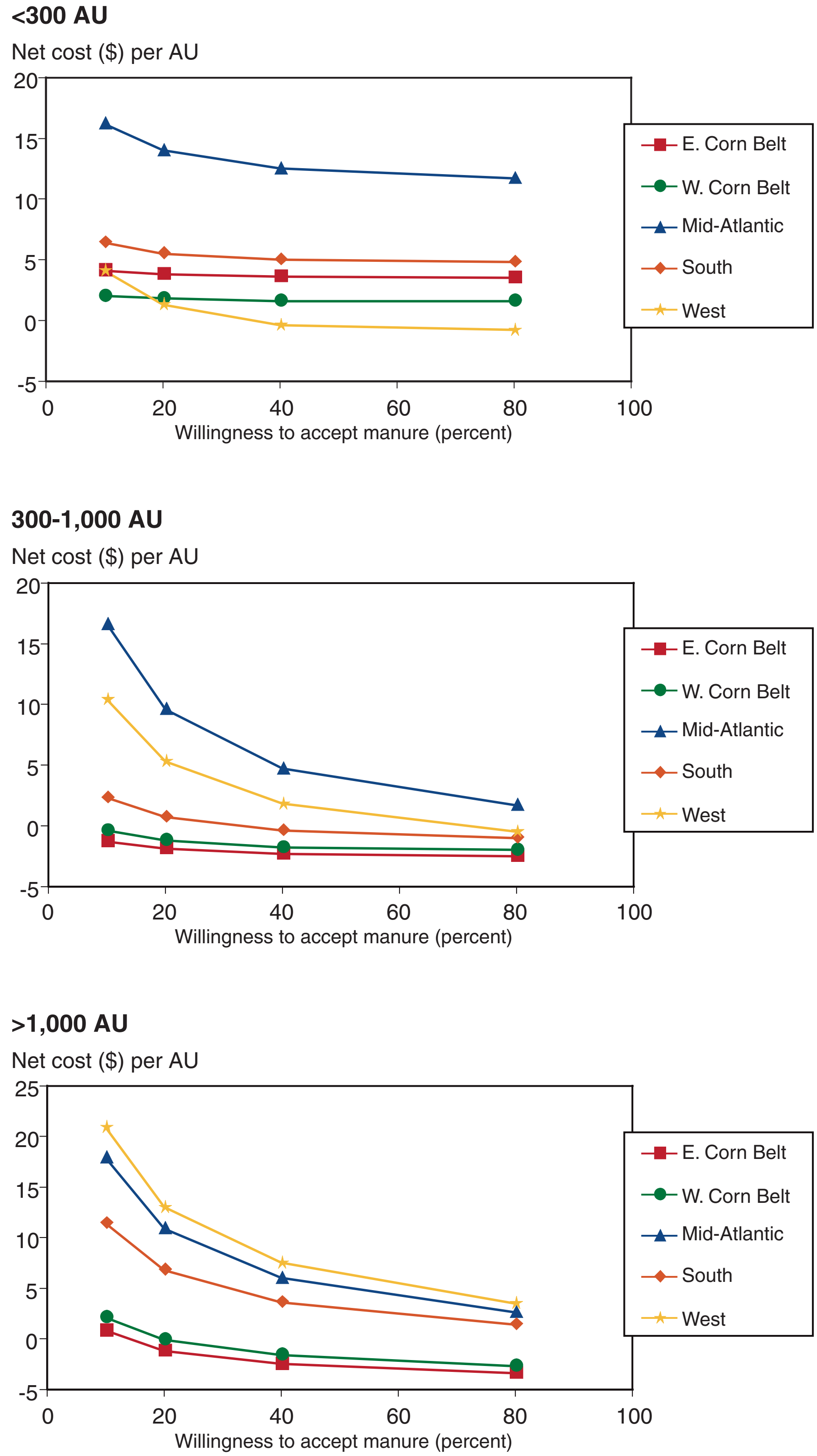
Figure 13
Increase in production costs for hog farms under a nutrient standard with a willingness-to-accept-manure of 20 percent, by size



Source: Ribaudo et al., 2003.

Figure 14

Net cost of spreading manure from hog farms following a phosphorus standard with all farms using phytase, by region



Source: Ribaudo et al., 2003.

Operations with fewer than 25 animals were eliminated from the analysis on the grounds that they were not confinement operations. Dairy farms were grouped into three size classes based on the EPA definition of animal unit, 0.7 mature dairy cows (Table 8). Two regions were considered, North and South.

Most small dairies would not have been affected by a nitrogen-based standard, as they were not overapplying manure N, although there are regional differences (Table 8). Most medium and large dairies generally do not own enough land for applying all their manure under an N-based standard, and must move some off the farm. As with hog farms, large operations would have to increase the amount of land receiving manure the most (Ribaudo et al., 2003) (Table 9). If farms were required to meet a phosphorus-based standard, the amount of land needed off the farm would increase substantially, as well as the number of farms needing to move manure off the farm.

The net costs of meeting a nitrogen based applications standard would be highest for medium-sized dairies (Figure 15). Even with a high willingness to accept manure, manure application costs are about $10 per AU for medium-sized dairies. For large operations, costs approach 0 as WTAM approaches 80 percent. Small operations also see costs that are higher than large operations. Meeting a P-based standard would increase the net costs of spreading manure for all size classes because of the larger amount of land needed for spreading (Figure 16). Costs approach $20 per AU for medium operations, even at high WTAM. Costs are much higher at lower WTAM.

Table 8

Percentage of dairy farms meeting N-based and P-based standards, by region and EPA size class, 2000

Region	Farms with confined dairy cows	Farms meeting N-based standard	Farms meeting P-based standard	Farms with adequate land for N-based standard	Farms with adequate land for P-based standard
	Number			*Percent*	
South					
<300 AU	1,998	19.5	4.8	33.2	18.4
300 – 1,000 AU	1,921	5.7	0	8.5	1.1
>1,000 AU	1,268	21.3	1.0	26.6	2.6
North					
<300 AU	55,622	72.1	27.3	91.2	66.4
300 – 1,000 AU	1,893	46.4	10.9	66.2	31.6
>1,000 AU	603	26.5	0	26.5	0
Nation					
<300 AU	57,620	70.8	26.7	89.8	65.3
300 – 1,000 AU	3,814	27.5	5.8	39.4	17.5
>1,000 AU	1,871	23.0	0.7	26.6	1.8

AU = 0.7 mature dairy cow.

Operations with fewer than 25 cows were dropped from the analysis

Source: Ribaudo et al. (2003)

Table 9

Estimated acreage being used for spreading and acreage needed to meet nutrient standard on dairy farms, by region and size, 2000

Region	Acres being used	Own available acres[1]	Acres needed: N-based standard	Acres needed: P-based standard
			Acres	
South				
<300 AU	52.6	76.5	143.4	262.0
300 – 1,000 AU	129.4	114.8	343.8	795.3
>1,000 AU	310.4	319.6	661.3	2001.0
North				
<300 AU	100.7	207.0	63.6	147.2
300 – 1,000 AU	328.3	584.0	338.8	756.8
>1,000 AU	330.9	391.4	564.2	1,979.0
Nation				
<300 AU	99.5	203.8	65.6	150.1
300 – 1,000 AU	235.9	366.0	341.1	774.6
>1,000 AU	316.9	342.4	630.5	1,994.0

[1]Acres owned or leased suitable for receiving manure.

Source: Ribaudo et al. (2003)

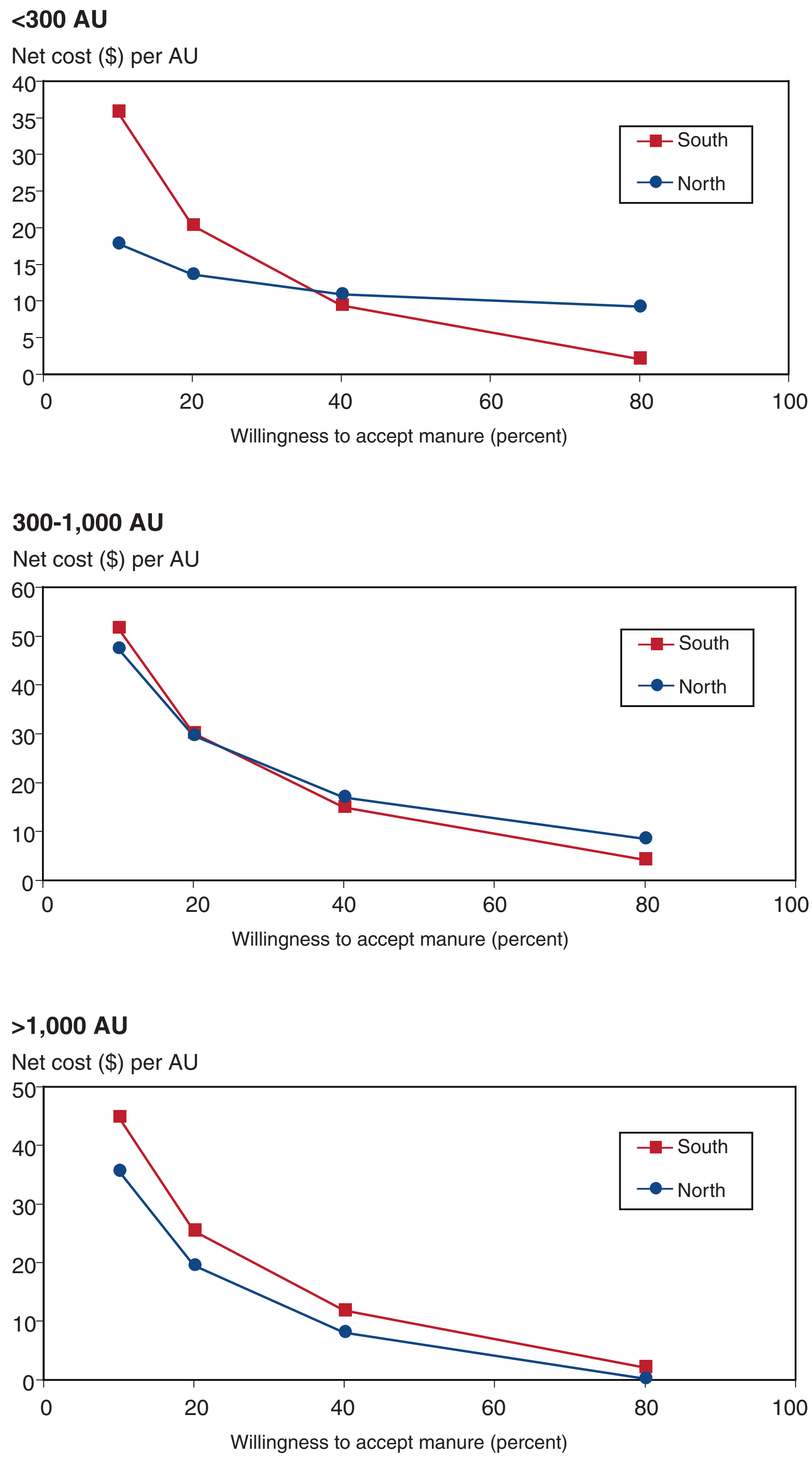
When viewed in relation to production costs (operating costs plus allocated overhead), the increase in costs from meeting a nutrient standard are relatively small, even when willingness to accept manure is low (Figure 17). As a percentage of production costs, impacts of a manure application standard would be about 1 percent or less for all regions and size classes, assuming a high willingness to accept manure (80 percent). Small operations saw the smallest impacts on production costs, primarily because of the adequacy of their land base. Even for a lower willingness to accept (20 percent), productions costs for any size class would increase less than 2 percent for an N-based standard, and less than 3.5 percent for a P-based standard.

Since 2000, dairy industry production has shifted to much larger farms. Farms with fewer than 100 cows accounted for 20 percent of all milk cows in 2008, down from 34 percent in 2000, while farms with at least 1,000 accounted for 42 percent of all cows in 2008, compared to 19 percent in 2000. An ARMS dairy version was again conducted in 2005, allowing for comparisons to the 2000 data used in Ribaudo et al. (2003).

The structural shifts, along with expanding regulation, have placed more production under nutrient management plans (49 percent of cows were covered by NMPs in 2005, compared to 40 percent in 2000). There was some increase in manure removal from farms, from 16 to 19 percent of all manure, between 2000 and 2005. Dairies could also take steps to alter feed formulations so as to reduce manure nutrients—operations covering 11 percent of all cows were adding phytase to diets in 2005.

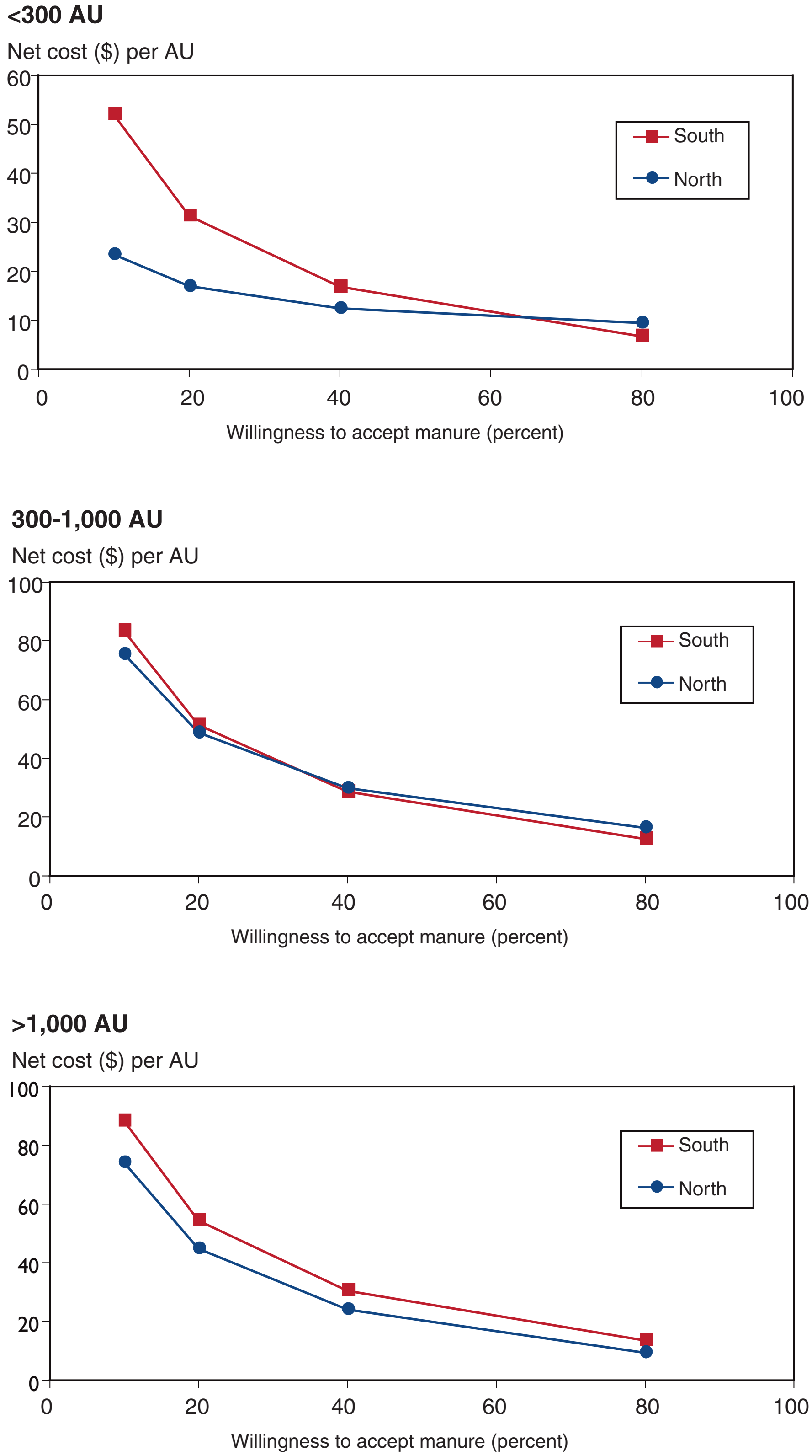
In general, large hog and dairy operations consolidate substantial amounts of manure, and continued structural change is leading to greater consolidation. Large operations will need to comply with regulations by expanding the amount of cropland that manure is applied to, either by operating more

Figure 15
Average cost of applying manure from dairy farms following a nitrogen-based standard, by region



Source: Ribaudo et al., 2003.

Figure 16
Net cost of spreading manure following a phosphorus-based standard, by region



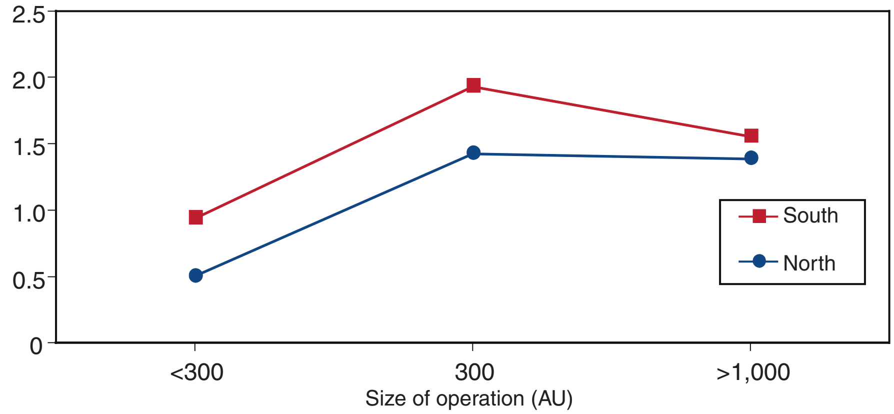
Source: Ribaudo et al., 2003.

Figure 17

Increase in production costs for meeting a nutrient standard with a willingness-to-accept-manure of 20 percent for dairy farms, by size

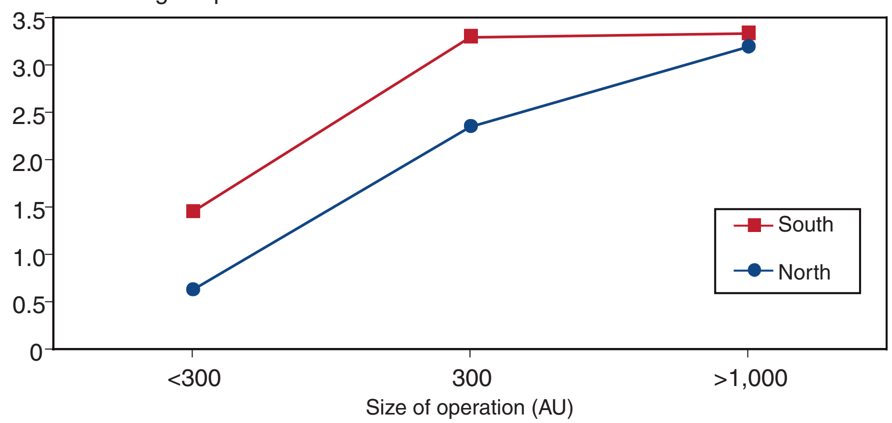
N-based standard

Percent change in production costs



P-based standard

Percent change in production costs



Source: Ribaudo et al., 2003.

manured acres on the farm or by removing manure to cropland on other farms, or they will need to reduce nutrient loadings through changes in feeding. The Ribaudo et al. (2003) estimates suggest that the likely costs required to meet NMPs, while substantial in the aggregate, are nevertheless relatively small fractions of total production costs. If those findings are accurate, they suggest that the cost advantages held by large farms will not be erased, or even substantially modified, by the types of regulations captured in nutrient management plans (in some cases, they are enhanced slightly). In that case, such regulations are unlikely to lead to major structural changes in the industries.[20]

[20]There may nevertheless be significant geographic changes in livestock feeding driven by differences in production costs, some of which may in turn be driven by future urban development, State and local moratoria on large operations, or persistent geographic differences in NMP compliance costs. Our evidence suggests that these factors may influence the location but not the size structure of production.

Competition from Energy Uses of Manure

There is growing interest in using manure as a feedstock for energy production, driven by rising energy prices and growing concerns over the environmental risks associated with excess applications of manure nutrients and with fossil fuel energy production. Two types of manure-based energy production are in current commercial use in the United States.[21]

[21]In this section, we rely on media reports, academic journal articles, and EPA databases for source data on manure-to-energy projects, and we use ARMS data to generate estimates of the potential avoided costs of on-farm electricity generation.

Anaerobic digesters are in use on dairy and hog farms, and a few community digesters also serve multiple operations in a local area. Digesters capture biogas, which contains methane, carbon dioxide, and trace amounts of other gases, from manure. The gas can be used as a fuel for boilers, heaters, chillers, and generators, but it can also be cleaned and conditioned for insertion into a natural gas (97 percent methane) pipeline. Most current applications burn the gas for on-farm electricity generation.

Manure can also be treated and burned as a feedstock in electricity generating plants. Manure must be transported from farms to centralized generating plants to realize scale economies in combustion. Several such plants are in operation in England and Scotland. A plant using fed cattle manure first operated in California in 1987; that plant is currently idled, but a plant relying on turkey litter recently opened in Minnesota, and others are under construction in Connecticut (using litter from an egg-laying operation) and Texas (using cattle manure).

Manure to Energy Systems in Current Commercial Use

In the manure storage systems that are typically used on large dairy and hog operations, little oxygen can dissolve into the mix, which creates anaerobic (without air) conditions. Certain microbes that are naturally found in manure feed on organic materials in the manure. The bacteria function best in anaerobic conditions, and they give off biogases, primarily methane and carbon dioxide. Methane is the primary component of natural gas and is a clean-burning fuel.

If methane can be captured from manure, it can be used as a feedstock for electricity generation. Farmers could then reduce their purchases of electricity and fuels, and might be able to sell excess electricity or methane. Society can gain because an existing product, manure-based methane gas, would replace some fossil fuels used for the same purpose. In addition, the manure effluent that is left after anaerobic digestion has few remaining decomposable compounds. Decomposition is what creates odor, so digestion also provides a solution to odor problems.[22]

[22]The gas that digesters capture is 60-70 percent methane and 30-40 percent carbon dioxide, another greenhouse gas. Carbon dioxide could be separated, refined, and cooled for industrial uses, but that would require additional capital investment.

Anaerobic digestion presents several important technical challenges in on-farm applications. An anaerobic digester is a sealed air-tight container that more effectively excludes oxygen from the manure and encourages a higher level of biogas production. Manure is added daily to the digester, and spends about 20 days flowing through the digester to the effluent storage and handling system. Growth of methane bacteria can be encouraged by maintaining higher temperatures, so heat must usually be added to a digester—typically via pipes running through the digester—and regulated for maximum gas production. The bacteria are quite pH-sensitive, so high alkalinity must be maintained in digesters, through added ingredients (lime) and by carefully regulating the flow of organic material to the digester. A variety of materials, such as salts, heavy metals, ammonia, and antibiotics, are toxic to methane bacteria, and must be carefully controlled.

The potential for generating methane is greatest when manure is collected and stored as a liquid, slurry, or semi-solid. Biogas potential is greatest at large dairy and swine operations because they use liquid or slurry manure management systems, and they have attracted the most attention. Manure managed in solid form, as in the fed cattle and poultry sectors, offers little opportunity for current digester designs.[23]

While there are a few centralized community digesters, most are on-farm systems. Manure can also be used as a feedstock for power plants, where the manure is incinerated and the heat from combustion creates steam for turning electricity-generating turbines. The manure produced on dairy and hog farms is costly to transport, and combustion is difficult to maintain with such high-moisture fuels, so combustion plants focus on poultry litter and fed cattle manure, which have high energy content and lower moisture content and transportation costs. The latter consideration is important because a power plant may draw in a large volume of manure from a significant catchment area.

But the moisture content of dry manure remains higher and more variable than non-manure feedstocks, making it harder to sustain combustion. Manure can create significant nitrous oxide emissions when burned, and it creates large volumes of ash residue. Some compounds added to feeds may present air pollution concerns when the litter is burned; on the other hand, manure is low in sulphur content compared to other fuels. These technical barriers stand in the way of widespread adoption of manure for energy production.

Extent of Current Adoption

Manure-to-energy systems are in limited commercial use in the U.S. By the summer of 2008, 91 commercial dairy farms were using digesters and another 64 had projects in the construction, design, or planning (CDP) phase. Farms in the two categories accounted for 0.2 percent of all dairy farms and 2.9 percent of all dairy cows in the U.S. (Table 10). In addition, the Environmental Protection Agency reports that 17 hog farms had operating digesters by the summer of 2008, with the manure supplied by 355,000 hogs. But that amounts to just 0.5 percent of the inventory of hogs and pigs on U.S. farms (0.6 percent when the 6 farms in the CDP phase were added).

Larger dairy and hog farms are more likely to adopt digesters, but adoption is not widespread even among them (Table 11). About 4.5 percent of dairy farms with at least 2,000 cows have digesters, and another 3.4 percent are in the CDP phase, but they account for just 8 percent of the cows on dairy farms with at least 2,000 head.[24]

Combustion plants are still in their commercial infancy in the U.S. An 18.5-megawatt plant in El Centro, California, was opened in 1987 and utilized the

[23] A large digester under construction in Alberta, Canada, will use cattle feedlot manure and a newly developed separation technology to remove sand and dirt from the manure before digestion (Kryzanowski, 2009). The biogas will be used to generate electricity to power an onsite ethanol plant, with excess electricity to be sold into the power grid.

[24] Most of the hog operations with digesters had at least 5,000 hogs in inventory, which is a relatively large hog feeding operation, and two large complexes had over 100,000.

manure produced by 100,000 cattle, just under 1 percent of all feedlot cattle. The plant was idled but acquired by GreenHunter Energy in 2007, which expects to reopen the plant by 2009. The plant has a 30-year supply contract with a California utility.

A large combustion plant was opened in Benson, Minnesota, in May of 2007. The plant, called Fibrominn, sells the electricity it generates to Xcel Energy, a Minnesota-based public utility, under a 21-year contract. The plant's 55-megawatt generating capacity helps Xcel meet a mandate set by the Minnesota legislature for each of the State's utilities to realize 125 megawatts from biomass or wind power.

The Benson plant utilizes turkey litter from about 300 farms within a radius of 100 miles. The farms currently supplying the plant account for about 40 percent of Minnesota turkey production, or about 6.6 percent of U.S. turkey production, although they do not provide all of their litter to Fibrominn (some is used on-farm as fertilizer). Fibrominn was financed by Fibrowatt, a company whose management developed four poultry-litter plants in the

Table 10

Anaerobic digesters on dairy farms, by region

States	Total milk cows	Farms and cows, by status of digester projects			
		Steady state/start-up		Construction/ Design/Planned	
		Farms	*Cows*	*Farms*	*Cows*
CA	1,780,000	15	28,162	4	10,795
Other West*	1,345,000	11	27,275	3	6,650
IN/MI/OH	759,000	4	12,400	10	44,870
NY/PA/VT	1,333,000	29	26,943	23	28,370
WI	1,243,000	19	28,000	13	15,750
IA/IL/MN	758,000	6	7,350	11	15,900
All	9,112,000	91	139,505	64	122,335

*ID/OR/TX/UT/SD/WA

Source: U.S. Environmental Protection Agency, Agstar Program, Anaerobic Digester Database.

Table 11

Farm size and adoption of anaerobic digesters

Herd size of farm	All U.S. dairy farms		Farms with digesters, by status			
			Steady state/startup		Construction/ Design/Planned	
	Farms	*Cows*	*Farms*	*Cows*	*Farms*	*Cows*
<500	68,295	4,656,000	18	4,973	8	1,575
500-999	1,700	1,139,000	22	16,424	16	11,450
1000-1999	920	1,212,000	24	31,107	20	27,010
>1999	595	2,106,000	27	87,001	20	82,300
All farms	71,510	9,112,000	91	139,505	64	122,325

Source: U.S. Environmental Protection Agency, Agstar Program, Anaerobic Digester Database.

United Kingdom. Fibrowatt is pursuing projects for similar plants in major broiler producing regions in North Carolina, Maryland, Arkansas, and Mississippi. Although the company has announced a site in North Carolina, construction has not commenced there or at the other locations.[25]

Another combustion plant has been proposed in Bozrah, Connecticut, by Clearview Renewable Energy. The 30-megawatt plant would utilize litter from a large egg-laying operation (340 tons a day) and waste wood from pallets and tree trimmings. It has received approval from the State's utility board and a site on the egg farm has been selected, but construction has not begun.

Panda Ethanol has a plant under construction in Hereford, Texas, which would use manure from feedlots to generate the steam needed to operate an ethanol refinery. The plant would gasify about 500,000 tons of manure a year; feedlots within 50 miles of the plant generate 2.1 million tons annually. Panda has announced plans to build three other plants, although the Hereford plant is the only one currently under construction.

Drivers of Adoption

Few manure-to-energy projects are now in commercial operation, but there is widespread interest in such projects and considerable potential for future growth. In order to understand the prospects for future growth, and the limits to current adoption, it is important to understand the incentives faced by individual decision makers.

Centralized combustion facilities require a substantial capital investment. Even though Fibrominn secured an agreement to sell its electricity to Xcel in August of 2000, it was unable to secure the $202 million in financing for the plant from a consortium of insurance companies until late 2004.

Moreover, Fibrominn's costs of electricity generation exceed those at conventional coal-fired plants, even though the plant's size allows it to realize lower costs than smaller biomass facilities. A Minnesota legislative mandate, requiring Xcel to generate 125 MW of power from biomass and wind sources, played an important role in securing the electricity supply contract for Fibrominn. Public support, either indirectly through mandates or directly through payments, may be critical for widespread adoption of manure-to-energy systems.[26]

Specific location also plays an important role. A viable combustion plant needs large local supplies of excess litter to minimize its costs of purchasing and transporting fuel, as well as easy transmission connections to limit its cost of transporting electricity.

The Fibrominn plant burns about 2,000 tons of litter a day. Half is acquired under long-term contracts from farmers in the immediate area, and the rest is trucked in from farms within a 100-mile radius. The plant pays farmers a price, 3-5 dollars per ton of litter, that matches what they can earn from selling the litter for fertilizer. The plant is also located near a new 115-kilovolt transmission line, and a co-located plant produces and sells phosphate fertilizer from the ash residue of the combustion process.

[25]Broilers are an attractive potential feedstock because broiler production generates about 6 times as much litter as turkey production, based on ASAE standards for per animal manure production by broilers, male turkeys and female turkeys, ASAE estimates of the fraction of males in turkey production, and USDA estimates of annual broiler and turkey slaughter.

[26] The proposed Clearview plant in Connecticut is expected to cost $140 million. The project was spurred by a legislative mandate imposed on Connecticut utilities, and financing was secured through the offer of long-term supply contracts offered to renewable energy providers by a State agency.

The California plant is located in California's Imperial Valley, with 400,000 head of feedlot cattle within a 20-mile radius. When operating, the plant took about one-quarter of the area's manure. The proposed Connecticut plant would be located on an egg farm; with limited crop production in the area, the farm faces a problem of excess nutrients. The Texas ethanol plant, now under construction, is located in a dense region of cattle feedlots, and has contracted to acquire manure for no cost, save for the expense of trucking it to the site.

Most anaerobic digesters are on-farm systems, so the costs and benefits facing the individual farmer are crucial in adoption.

The costs include:

- Capital costs, for digester and generation equipment;
- Operation and maintenance (O&M) expenses;
- Costs of adapting existing manure handling and storage to biogas systems; and
- The farmer's time costs in learning about and maintaining the system, which could amount to an hour a day.

The financial benefits include:

- Avoided costs of electricity, if the biogas is used onsite for generation that replaces electricity purchased from the electric utility;
- Avoided propane, fuel oil, or natural gas purchases, if waste heat is recovered from generation and used for space and water heating;
- Revenues from the sale of excess electricity to the local utility, or from the sale of methane gas (each requires additional costs);
- Avoided costs—or revenues from sales—of bedding made from digested solids;
- Avoided costs of commercial fertilizer and herbicides deriving from an improved fertilizer value of digester effluent over raw manure; and
- Revenues from the sale of carbon credits in greenhouse gas markets.

We used ARMS Phase III data to analyze the avoided costs of electricity and fuel purchases on dairy and hog operations. Farm size matters. A typical Northeastern dairy farm with 200 cows spent nearly $29,000 on electricity, propane, and natural gas expenses in 2005, and that expense rose to $63,000 on farms with 500 cows, and $114,000 on farms with 1,000 cows. Larger farms have a much stronger incentive to seek out investments that will allow them to replace purchased electricity, while small farms with digesters would need a market outlet for their electricity. But among farms of a given size, expenses can vary widely, and so can the incentives for digester adoption, with differences in farm production practices and location.

Location matters because prices for electricity vary across the country and variations in climate affect heating and cooling demand. In 2006, the average nationwide retail electricity price paid by firms in the commercial sector was 9.46 cents a kilowatt hour, but State-level averages ranged from 5.16 cents in Idaho, the 4th largest dairy State, to 16.3 cents in New York, the 3rd largest.[27] Propane and natural gas prices varied much less across States. Electricity and fuel usage can also vary because of differences in farm organization and technology.

Farms that milk three times a day use more electricity and fuel than those that milk twice a day, as do those with older milking systems. Farms that grow more crops, either for feed or for sale, use more electricity and fuel, holding herd size constant. Farms that use pasture for some of their forage, that raise heifers off-site, or that dry cows off seasonally, use considerably less, as do farms that keep cows in dry lots.

The impact of these differences can be quite large. Farms in the Northeast and Western Corn Belt have substantially higher electricity, propane, and natural gas expenses than similarly sized farms in the West, South, and Eastern Corn Belt. If a typical 500-cow Northeastern dairy spent about $63,000 on those expenses in 2007, a dairy with 500 cows but with production practices more common for Western operations would spend about $28,000. Moreover, a Western operation with 1,000 cows would spend about $51,000, still well below expenses at a 500-cow Northeastern dairy.

Hog production has also shifted to much larger operations, but the way hog production is organized has also changed. Traditional farrow-to-finish operations, covering all stages of production, are being replaced with farms specializing in specific stages of production. As a result, the volume of manure per animal varies considerably, depending on the farm's specialty. In addition, production is usually coordinated by an integrator that provides feed and feeder pigs to contract farmers, who grow the pigs to market weight. The farmer provides labor and capital services while the integrator retains ownership of the pigs and handles their disposition when they reach market weight. Integrators can have an important impact on adoption, both directly through their own actions and indirectly through the design of contracts with growers.

Electricity and fuel expenses increase with the volume of hog production, so larger operations are likely to see greater gains from investment in digesters. The EPA estimates that digesters are economical for operations with at least 2,000 hogs, but conditions vary considerably, even among large operations. Some have deep-pit manure storage systems that would require costly retrofitting for digester adoption. Avoided costs also vary widely across apparently similar operations. For a given number of market hogs produced, drylot operations have substantially lower electric and fuel expenses; farrow-to-finish operations have substantially higher expenses than feeder-to-finish operations; and hog farms with significant crop production have substantially higher electric and fuel expenses. Few finishing operations remove more than 10,000 hogs/year, and electricity and fuel expenses for those with no crop production are unlikely to exceed $10,000. By contrast, those with substantial cropping operations may have expenses reaching $40,000-$50,000. As in dairy, location matters, with electric and fuel expenses substantially higher in eastern hog production States than in Corn Belt and Plains States.

There have been several other recent analyses of digester adoption. Leuer, Hyde, and Richard (2008) analyzed incentives for adoption on Pennsylvania dairy farms, and included the potential for additional revenues from sales of

[27] According to data from the Energy Information Administration, at http://eia.doe.gov.

electricity or carbon credits. Their analysis showed that larger operations were more likely to profit from a digester, but their findings suggested that farms would have to be quite large, on the order of 1,000 to 2,000 head. Profits from adoption were quite sensitive to the digester's initial capital cost.[28] Changes of 10 percent from a base case cost had large impacts on the profitability of adoption, an important finding when estimates of capital costs still vary widely.

[28]USDA Rural Development has supported investments in anaerobic digesters through grants and loans. In the six years covering 2003-2008, USDA provided grants of $40.6 million, and loans of $19.1 million, in support of 121 digester projects.

Profits were also quite sensitive to the availability of revenues from the sale of electricity or carbon credits. Few large dairies would find a digester investment to be profitable without significant support for capital costs, carbon credit revenues, or revenues from electricity sales. To realize revenues from electricity sales, farms must connect their biogas-fired generators to the electrical power grid, an action that raises safety, power quality, technical, legal, and procedural issues. Farms must often make additional capital investments to support connection, and they will often need to hire technical experts for information and guidance in negotiating contracts. Utilities are often reluctant to purchase excess electricity from farmers, and when they do are likely to offer rates reflective of their avoided generation costs, which are generally well below retail rates. Opportunities to sell electricity are dependent on regulatory or legislative support in the State, so public policy will play a major role at the margin in driving adoption.

Farmers may qualify for carbon credits if they can capture methane and prevent it from emitting into the atmosphere. If farmers can provide credible claims of reduction in methane emissions, they may be able to sell the carbon credits in private transactions or in organized exchanges, thereby gaining further revenues from an investment in a digester. Credits traded on the Chicago Climate Exchange (CCX) varied over 2008 from $1.90 per metric ton to $7.40, with a mean price of $4.98 (Liebrand and Ling, 2008). If a lactating dairy cow produces five metric tons of methane in a year (five credits), then the farm could realize $25 per cow per year from the sale of carbon credits at a credit price of $5, and a farm with 1,000 cows could realize $25,000 in additional revenues. The farmer who had already invested in an anaerobic digester would bear some additional costs of qualifying for credits, for metering equipment and for fees paid to intermediaries, but the additional net revenues could make the project as a whole profitable.

The costs to be borne by farmers for digester adoption, as well as the benefits accruing to them, are subject to considerable uncertainty. Stokes, Rajagopalan, and Stefanou (2008) examined the impacts of uncertainty on digester adoption among Pennsylvania dairy operations. They conclude that uncertainty can play a major role in deterring adoption, and that grant funding might be necessary to induce farmers who are uncertain about the value of the completed project to invest in digester adoption.

Impacts on Fertilizer Uses for Manure

Only a small fraction of dairy manure is currently used for energy production through anaerobic digesters, with another small fraction in the CDP phase. If all current projects stayed in use, and all those in CDP phase were added, they would still account for less than 3 percent of the manure from dairy cows in the U.S. An even smaller share of hog manure is directed to energy use through digesters. Less than 1 percent of fed cattle manure, and less than 10 percent of turkey litter, is used in combustion energy processes, and we know of no current energy operations using broiler litter.

However, more large dairy and hog farms, and more contract poultry farms, could find energy operations to be profitable options if energy prices were to rise, or if producers could realize additional revenue from the sale of electricity, gas, or carbon credits. Production is continuing to consolidate among larger hog and dairy operations for whom digester use is potentially feasible, and there could be a movement into digester use if the economics of the investment were to improve. Would a major shift toward energy production divert manure away from use as fertilizer?

Anaerobic digestion has one important feature that matters here: the N, P, and K fertilizer nutrients present in raw manure are retained in the effluent from the digestion process. Digestion reduces pathogen counts and denatures weed seeds in raw manure, and the odors of raw manure are greatly reduced in the effluent, thereby easing the storage, movement, and application of manure nutrients. As a result, anaerobic digestion may increase the fertilizer value of raw manure.

Since the volume of liquid digester effluent is unchanged from the amount of liquid in the raw manure entering the digester, the effluent will still be costly to ship.

Digesters are often used in combination with solids separators, although separators may also be used on farms without digesters. The liquid effluent from separation is usually stored in lagoons and sprayed on crops as fertilizer. The solids may be used as bedding for cows, or they may be sold as compost to commercial and residential buyers. The nutrients that are retained in the solids are therefore lost to farming operations. However, it seems likely that if the solids had real value as crop nutrients, farmers would have used them as such instead of bearing the additional expense of turning them into compost.

Most nitrogen nutrients are burned during combustion processes. But the ash residues from combustion retain phosphorus and potash nutrients, in concentrated form because the process leaves about one pound of ash for every five pounds of turkey litter. Combustion plants market the ash residue as fertilizer to farmers, and indeed Fibrominn located a fertilizer processing plant on site next to its generating facility. The transportation costs of the resulting fertilizer product are substantially reduced because of its lower weight and volume, which creates a larger market area for sales.

The fertilizers derived from combustion processes might not be sold to farmers, and the nitrogen nutrients in the manure will be lost to crop fertilization, but local market forces play an important role here as well. Operators of combustion facilities purchase their manure feedstock, and operation will be most profitable in those areas with low prices for manure. Those are likely to be locations with excess manure nutrients and, therefore, a very low value for manure used locally.

Conclusions

Livestock manure has value for farmers because it contains nutrients that facilitate plant growth and because manure can improve soil quality by increasing organic matter, neutralizing acidity, and expanding the water-holding capabilities of soils. However, manure may not have the precise combination of nutrients needed for optimal crop production in a given field. It is costly to move, and crops in modern agriculture may be produced at some distance from livestock. Manure odors may offend neighbors, and manure may contain a variety of pathogens.

Extent to which Animal Manure is Used as a Fertilizer

About 15.8 million acres of cropland, equivalent to about 5 percent of all U.S. cropland, are fertilized with livestock manure. This estimate is based on data drawn from several sources and is subject to some uncertainty. Nevertheless, it is clear that manure is used on only a small fraction of U.S. cropland.

Patterns of manure use are driven by the agronomic needs of crops and by transport costs, which limit the distance that manure can be moved and create close links between types of livestock and certain crop commodities. In particular, dairy cow and hog manure tend to be collected in a slurry, and the high moisture content of slurry creates even higher transport costs. But the manure can be applied on-farm to corn; with its high nutrient uptake, particularly for nitrogen, corn is an attractive option for livestock operations seeking to utilize manure, and corn provides a livestock feed. As a result corn, which has accounted for about one-quarter of planted crop acreage in recent years, accounts for over half of the acreage to which manure is applied.

In contrast, drier manure from poultry and cattle feedlot operations has lower transportation costs. Manure from those farms is more likely to be removed and shipped to other operations, and it is spread over a wider range of commodities. Because broiler production is concentrated in the southern United States, crops like peanuts and cotton rely heavily on broiler manure when they use manure fertilizers.

Potential Impact from Limitations Placed on Use of Animal Manure

Livestock production has shifted to much larger operations, which also consolidate large quantities of manure in limited geographic areas. The quantities of manure nutrients produced on many large livestock operations exceed the capacity of the farm's crops to absorb them, a problem that extends beyond individual farms to some regions where aggregate manure nutrient production exceeds the region's crop nutrient needs. Excess nutrients can lead to water and air pollution.

In response to environmental risks, Federal, State, and local authorities are expanding their regulation of manure storage, transport, and application. Many operations now must prepare, file, and comply with detailed plans for managing manure so as to limit the possibilities for catastrophic spills or for land application in excess of the agronomic needs of crops. Some need to change manure management practices to comply with the plans. They will need to acquire more land for manure application, arrange with other farmers to accept manure for their cropland, reduce the nutrient content of manure, reduce manure production, or find other uses for manure.

Estimated costs of compliance vary with the degree to which nearby farmers are willing to accept manure for application to their cropland, because a low willingness to accept among nearby farmers means that livestock producers will need to transport manure much farther for crop application. Costs also vary with the size and location of the operation, and with the particular type of nutrient management plan (standards may be set for nitrogen or for phosphorus).

With a limited willingness to accept manure (defined as 20 percent of nearby farmers), production costs, including those for manure management, would likely rise by 2.5-3.5 percent for large operations (Ribaudo et al., 2003). Such costs are unlikely to alter the size structure of livestock production, where large operations have substantial cost advantages over small operations. They are also unlikely to lead to substantial declines in production and consumption; the resulting percentage increases in retail prices would be less than those noted above because farm costs are only a fraction of retail costs, and retail demand for meat and milk is relatively insensitive to price changes. As a result, expanded regulation through nutrient management plans will likely lead to wider use of manure on cropland, at higher production costs, with little impact on farm structure.

Effects on Agricultural Production due to Increased Competition for Manure for Energy Production

There is widespread interest in using manure as a feedstock for energy production. Current examples include combustion power plants and anaerobic digestion systems designed to capture methane gas and burn it as fuel for electricity generation. While each technology is in commercial use in the United States, neither is widespread. Digester systems, either planned, in construction, or in operation, cover less than 3 percent of dairy cows and less than 1 percent of hogs. The single operating combustion plant utilizes litter from 6.6 percent of U.S. turkey production, while an idled plant in California could utilize manure from about 3 percent of fed cattle.

Farmers who produce electricity through digesters can benefit from avoided purchases of electricity, but few can realize enough savings to justify the expense. Similarly, farmers can generate additional revenue from sale of manure to combustion plants, but few potential plant operators have found the economics to be attractive. But because such projects use existing resources, they could provide society with benefits if manure replaces newly mined fossil fuels in energy production, and if methane, a greenhouse gas, can be captured. Those societal benefits have led to proposals to support the use of manure for energy projects through State utility mandates (to purchase electricity from farms and to invest in renewable production sites), subsidies for capital costs, and direct subsidies and credits for energy production. Expanded support could lead to a substantial growth of energy applications for manure. In turn, that leads to a concern that expanded energy uses might compete with fertilizer uses for manure.

Energy projects are unlikely to impose substantive constraints on the use of manure as fertilizer, for two main reasons. First, the technologies do not consume the nutrients in manure that are beneficial for plant growth. In the case of digesters, the nitrogen, phosphorus, and potassium nutrients remain in the effluent of the digester process, to be spread on fields. To the extent that digestion eliminates manure odors and nearly eliminates pathogens in manure, the process may make neighboring farmers more willing to accept manure for cropland application. Combustion plants do burn nitrogen nutrients but leave the phosphorus and potassium in concentrated form in ash residues. Second, manure-to-energy projects function in markets for fertilizer and energy and will be most economical in those areas where the acquisition costs of manure are lowest. In turn, manure acquisition costs will be lowest where manure is in excess supply, with the least value as fertilizer.

References

American Society of Agricultural Engineers. "Manure Production and Characteristics." ASAE Standard. ASAE D384.2. March 2005.

Baranyai, Vitalia, and Sally Bradley. "Turning Chesapeake Bay Watershed Poultry Manure and Litter into Energy." Chesapeake Bay Program Office. CBP/TRS-289-08. January 2008.

Gollehon, Noel, Margriet Caswell, Marc Ribaudo, Robert Kellogg, Charles Lander, and David Letson. *Confined Animal Production and Manure Nutrients*. U.S. Department of Agriculture, Economic Research Service. AIB-772. June 2001.

Huang, Wen-Yuan. "Factors Contributing to the Recent Increase in U.S. Fertilizer Prices, 2002-08." U.S. Department of Agriculture, Economic Research Service. *Agricultural Resources Situation and Outlook* No. (AR-33). February 2009.

Key, Nigel, William D. McBride, and Marc Ribaudo. *Changes in Manure Management in the Hog Sector, 1998-2004*. U.S. Department of Agriculture, Economic Research Service. EIB-50. March 2009.

Kotrba, Ron. "Generating Poultry Power." *Biomass Magazine*. July 2007.

Kramer, Joe. Wisconsin Agricultural Biogas Casebook. Report prepared for Focus on Energy-Renewables Program. July 2008.

Kryzanowski, Tony. "$100 Million Invested in Bio-energy expansion and Ethanol Plant." *Manure Manager*. January/February 2009.

Leuer, Elizabeth R., Jeffrey Hyde, and Tom L. Richard. "Investing in Methane Digesters on Pennsylvania Dairy Farms: Implications of Scale Economies and Environmental Programs." *Agricultural and Resource Economics Review* 37 (October 2008): 188-203.

Liebrand, Carolyn, and K. Charles Ling. "Carbon Credits for Farmers." U.S. Department of Agriculture. Rural Development. *Rural Cooperatives* 75 (November 2008): 10-12.

MacDonald, James M., and William D. McBride. *The Transformation of U.S. Livestock Agriculture: Scale, Efficiency, and Risks*. U.S. Department of Agriculture, Economic Research Service. EIB-43. January 2009.

Martin, John H. "A Comparison of Dairy Cattle Manure Management with and without Anaerobic Digestion and Biogas Utilization." Report submitted to the U.S. Environmental Protection Agency under Contract No. 68-W7-0068. June 2004.

Martin, John H. "An Evaluation of a Mesophilic, Modified Plug Flow Anaerobic Digester for Dairy Cattle Manure." Report submitted to the U.S. Environmental Protection Agency under Contract No. GS-10F-0036K. July, 2005.

Martin, John H. "An Evaluation of a Covered Anaerobic Lagoon for Flushed Dairy Cattle Manure Stabilization and Biogas Production." Report submitted to the U.S. Environmental Protection Agency under Contract No. GS-10F-0036K. June 2008.

Post, Tim. "Fibrominn Powers Ahead with Turkey Litter." Minnesota Public Radio. June 18 2007.

Ribaudo, Marc, Noel Gollehon, Marcel Aillery, Jonathan Kaplan, Robert Johansson, Jean Agapoff, Lee Christensen, Vince Breneman, and Mark Peters. *Manure Management for Water Quality: Costs to Animal Feeding Operations of Applying Manure Nutrients to Land*. U.S. Department of Agriculture. Economic Research Service. AER-824. June 2003.

Stokes, J.R., R.M. Rajagopalan, and S.E. Stefanou. "Investment in a Methane Digester: An Application of Capital Budgeting and Real Options." *Review of Agricultural Economics* 30(4)(2008): 664-676.

U.S. Department of Agriculture. National Agricultural Statistics Service, *Acreage*. June 2006.

U.S. Department of Agriculture. National Agricultural Statistics Service. *Farms, Land in Farms, and Livestock Operations*. February 2009.

U.S. Department of Agriculture. Natural Resources Conservation Service. *An Analysis of Energy Production Costs from Anaerobic Digestion Systems on U.S. Livestock Production Facilities.* Technical Note 1. October 2007.

U.S. Environmental Protection Agency. *Market Opportunities for Biogas Recovery Systems: A Guide to Identifying Candidates for On-Farm and Centralized Systems.* EPA-430-8-06-004. August 2004.

Glossary

Anaerobic digester – Storage system that stores manure under anaerobic conditions (without oxygen). Under these conditions, decomposition of organic waste by bacteria results primarily in methane and carbon dioxide biogases. The gases can be burned to generate electricity.

Animal unit (or AU) - a standardized measure used in USDA statistical and regulatory programs to allow comparisons of manure production and feed needs across species. For example, some systems define an AU to be 1,000 pounds liveweight, so that four 250-pound hogs, or 200 5-pound broiler chickens, would each constitute one AU.

ARMS – Agricultural Resource Management Survey, an annual survey of farm finances and production practices that is carried out annually by the Economic Research Service and the National Agricultural Statistics Service.

Biogas – Gases produced by the biological decomposition of organic matter.

Broiler – Young chicken grown for meat.

CAFO – Concentrated animal feeding operation, a term developed by the Environmental Protection Agency for use in regulation. Animal feeding operations are agricultural operations where animals are kept and raised in confined conditions; feed is brought to the animals rather than the animals grazing or seeking feed in pastures, fields or rangeland. Concentrated operations meet certain additional EPA guidelines for operation size and proximity to water sources.

Commercial fertilizer – A substance, containing one or more recognized plant nutrients, that is designed to promote plant growth and that is manufactured from substances, such as natural gas or phosphate rock, that have been chemically altered.

Corn silage – Corn silage is a high-energy feed, used primarily for ruminants like cattle or sheep, that is created from fermentation of the entire green plant (and not just the grain).

Crop nutrients – Sixteen chemical elements are known to be important to plant growth and survival. Three—hydrogen, oxygen, and carbon—are non-mineral nutrients while the other thirteen are minerals. Among the minerals are three primary macro-nutrients: nitrogen (N), phosphorus (P), and potassium (K). Primary macro-nutrients are often lacking in the soil because plants use large amounts for growth and survival, and they hence are often provided through fertilizers.

Dairy cow – Female cow that has had her first calf and is used to produce milk commercially.

Dry cow – A dairy cow who is not producing milk. Typically, a farmer will stop milking a cow for the two months prior to an upcoming birth, in order to relax her and build up strength for the birth.

Farrow-to-feeder – Hog operation that contains breeding females (sows) and that raises pigs from birth until they are weaned and attain a feeder weight of 30-80 pounds.

Farrow-to-finish – Hog operation that contains breeding females and that raises pigs from birth to a slaughter weight of 225-280 pounds.

Fed cattle – Beef cattle fed for slaughter in specialized operations called feedlots. Most beef cattle are raised on pasture, fields, and rangeland before being shipped to feedlots, and some are raised to slaughter weight without being shipped to feedlots.

Feeder-to-finish – Hog operation that takes feeder pigs of 30-80 pounds and feeds them to a slaughter weight of 225-280 pounds.

Feedlot – Beef cattle operation that take young cattle, weighing 400-800 pounds, and feeds them to a slaughter weight of 1100-1300 pounds. Feedlot cattle are confined in pens and fed specialized diets of grains, oilseed meals, and other nutrients.

Heifer – Young female cow who has yet to give birth. Heifers may be used as replacement cows for beef or dairy production, or they may be fed to slaughter weight and used only for beef production.

Integrator – A firm or farm that contracts with other farms to raise livestock or poultry for it. Integrators typically provide young livestock or poultry and feed to the farm; they may sell the mature animals to processors, or the integrator may also operate processing facilities.

Litter – Poultry litter consists of poultry manure; bedding material such as sawdust, sand, wood shavings, or straw; and feathers and spilled feed.

Manure – Organic matter derived from animal production, which includes feces, urine, hair or feathers, and blood. Usually used as plant fertilizer, although it can also be used as a feedstock for power generation, and processed manure may be used as bedding for livestock.

Methane – A chemical compound with the molecular formula CH_4. The principal component of natural gas, it is also a relatively potent greenhouse gas with a high global warming potential. Livestock, primarily cows, are a source of methane.

NMP – A nutrient management plan, which specifies a set of information and conservation practices designed to use commercial fertilizers and manure effectively while protecting against the potentially adverse effects of nutrient storage and application and water and air quality.

Steer – Castrated male cattle, typically used for beef production.

Weanling to feeder – Hog operation that takes just-weaned pigs and raises them to a feeder weight of 30-80 pounds.