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.