Land application of manure by animal feeding operations: Is more land needed?

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ABSTRACT: Animal manure has become a major focal point of conservation efforts. A shift in the industry over the past decade towards fewer, larger operations has resulted in concerns over the utilization and disposal of animal manure. Land application of manure, a preferred disposal method, may be difficult and costly to implement on larger operations if restrictions on land disposal increase the amount of land required for spreading. The hog sector provides an example of how restrictions on manure application rates can affect the need for land. Using data from the 1998 Hog Agricultural Resource Management Survey we found that most confined hog operations would need to increase the land receiving manure to meet the needs of a nitrogen-based (N-based) or phosphorus-based (P-based) nutrient management plan. Both are possible under proposed Clean Water Act regulations by the Environmental Protection Agency (EPA) and program goals for the U.S. Department of Agriculture. Smaller operations tended to have adequate land on the operation to meet the needs of a N-based plan in most regions. Larger operations generally had inadequate land for N-based plans. All large operations would need to find substantial amounts of additional land to meet the needs of a P-based plan.

Keywords: Animal feeding operation, assimilative capacity, manure, nitrogen, nutrient management plan, nutrients, phosphorus, phytase

Animal manure has become a major focal point of conservation efforts. A shift in the industry over the past decade towards fewer but larger operations has resulted in concerns over the utilization and disposal of animal manure. Land application of manure, a preferred disposal method, may be difficult and costly to implement on larger operations if restrictions on land application increase the amount of land required for spreading. Kellogg et al. (2000) used data from the 1997 Census of Agriculture to give an initial indication of the potential magnitude of the problem from all livestock and poultry operations. Gollehon et al. (2001) used data from the 1997 Census of Agriculture to estimate the potential magnitude of the problem from confined livestock and poultry operations. Neither of these studies had information on current manure handling practices. We used data from the 1998 Hog Agricultural Resource Management Survey to provide a more detailed assessment of the amounts of land confined hog operations will need to properly dispose of manure through land application, taking into account their current manure handling practices.

The number of farms with confined animals has declined dramatically and steadily over the period from 1982 to 1997 from 435,000 to 213,000 farms (Gollehon et al, 2001). This decline occurred primarily in the smaller (less than 300 animal units or AUs[1]) operations. In 1997 there were 109,586 of these smaller confined livestock farms, which still accounted for 92 percent of all confined livestock farms. During the same period, there was an increase in the number of medium and large operations. Numbers of medium sized operations (300 to 1000 AU) have grown by 4,400 farms to 13,560, accounting for about six percent of all confined livestock farms in 1997 (Gollehon et al., 2001). The number of large farms (more than 1000 AU) has more than doubled during the period to almost 4,000 farms, or two percent of all confined livestock operations.

The decrease in the number of total livestock farms occurred at the same time as a 10 percent increase in the number of confined animal unit (AU), which means that the average AU per farm has increased significantly. A decline in animals on farms with less than 300 AU (from 19.3 million AU in 1982 to 12.7 million AU in 1997) was more than offset by growth on medium-sized farms (4 to 6.4 million AU) and large farms (7.5 to 14.5 million) (Gollehon et al., 2001). The significant economic benefits from vertical coordination in the animal sector, particularly for poultry and swine, led to both larger operations and a geographic concentration of animal production (Martinez, 1999; McBride, 1997). In 1997, the largest two percent of all livestock farms contained 43 percent of animal units.

Land application is the predominant method for utilizing manure and recycling its nutrient and organic content (USDA-EPA, 1999). While animal numbers were increasing, available cropland and pastureland operated by confined operations on which to spread manure declined from an average of 1.4 hectares (3.6 acres) per AU in 1982 to 0.9 hectares (2.2 acres) per AU in 1997 (Gollehon et al., 2001). This was due to the increase in the number of animals on large operations that have smaller amounts of land per animal unit.

The reduction in land per animal unit has raised concerns that nutrients in manure are not being utilized by plants and are becoming increasingly likely to run off or to leach into water resources. A positive nutrient balance on land, defined as excess nutrients above crop requirements, can indicate a potential for environmental damage.

Policymakers are currently considering alternative mechanisms to link livestock operations with available cropland to increase the nutrient contributions of manure to crop yield, thus reducing potential environmental damages from residual nutrients (Gollehon et al., 2001). The Unified Strategy for Animal Feeding Operations, developed by the U.S. Department of Agriculture (USDA) and the Environmental Protection Agency (EPA) in 1999, states that:

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"Land application is the most common, and usually most desirable method of utilizing manure because of the value of the nutrients and organic matter. Land application should be planned to ensure that the proper amounts of all nutrients are applied in a way that does not cause harm to the environment or to public health. Land application in accordance with the CNMP (comprehensive nutrient management plan) should minimize water quality and public health risk"
(USDA-EPA, 1999, pp. 8-9).

Appropriate land application of manure is also an important component of the rules proposed by EPA for changing the way animal operations are handled under the Clean Water Act. Application rate is the single most important manure management factor affecting the potential for contamination of water resources by nitrogen from manure (Mulla et al., 1999). Applying nutrients in excess of crop need increases the potential for nutrient movement to ground and surface water. To fulfill part of the goals of the Unified Strategy and to mitigate the actual and potential water quality impacts posed by the largest animal feeding operations, EPA is revising the regulations for identified as Concentrated Animal Feeding Operations (CAFO) under the Clean Water Act (U.S. EPA, 2001). CAFO's currently require a National Pollutant Discharge Elimination System (NPDES) permit to operate. One of the proposed changes is to require CAFOs to develop and implement a nutrient management plan for applying animal manure and commercial fertilizer to cropland. The plan would be nitrogen- or phosphorus-based, depending on the phosphorus content of the soil, and would become part of the NPDES permit, which is required for the facility to operate. Violations of the permit would result in fines and/or closure.

The EPA proposal only affects those animal feeding operations determined to be CAFOs. However, the Unified Strategy and USDA have stated goals for all animal feeding operations not covered by the Clean Water Act regulations to voluntarily adopt comprehensive nutrient management plans. USDA is working towards this goal by providing education, technical assistance, and financial assistance to livestock producers.

Nutrients from animal manure. Historically, agriculture recycled nutrients from animal manure on the cropland and pastureland that provided the feed for livestock. As confined operations become larger and feed is supplied from outside the region, animal manure is likely to be viewed more as a disposal problem than as a nutrient resource. Data from the 1997 Census of Agriculture show that a large percentage of nutrients from manure exceed the agronomic demands of the cropland operated by the feeding operations, based on reported yields (Gollehon et al., 2001). Excess soil nutrients are prone to movement into waterways through runoff or leaching, where they may have negative impacts on water quality. Actual environmental impacts depend on the size of the excess, the farm nutrient management practices, the location of facilities and agro-ecological conditions such as soil type and climate (Jones, 2001).

Methods and Materials

Computation of manure nutrients from Census data was a three-step process based on that used by Kellogg et al. (2000). First, animal numbers were converted to an average annual animal units (AU) inventory from reported end-of-year inventory and annual sales data. Second, quantities of manure were computed by applying coefficients of manure production by animal type based on the biological definitions of AU. Third, the recoverable portion of the manure nutrients per ton of manure was computed by animal type after adjusting for appropriate losses during collection, transfer, and storage. Recoverable manure nutrients represent that portion of manure that can be collected and applied to land net of losses. All calculations were done on the basis of elemental nitrogen (reported here as N) and phosphate P_2O_5 (reported here as P).

Potential manure nutrient assimilation by the farms on which the nutrients were produced was also estimated. Assimilative capacity is an estimate of the amount of nutrients that could be applied to land without building up nutrient levels in the soil over time. In these calculations, the land area and the per-hectare nutrient removal in the production of 24 major field crops and pastureland applications were computed for each farm in the Census based on reported yields and area planted. Nutrient removal is the nutrients contained in the grain and other plant material that is removed from the field. The calculation of the amount of nitrogen needed to achieve a particular crop yield included a nitrogen efficiency factor to account for the fact that, generally, only about 70 percent of the nitrogen applied is available to the crop (Kellogg et al., 2000). Nutrients contained in plant residues left on the field are assumed to be available for future crops. Recoverable manure nutrient production on confined livestock farms was compared with crop and pasture assimilative capacity on those same farms to compute a farm-level "excess" of manure nutrients. This calculation process may overstate excess manure nutrients in some cases because some manure may be moved off farms. However, total excess nutrients were more likely to be understated because neither commercial fertilizer applications nor atmospheric deposition of nutrients were considered in this analysis.

Table 1 summarizes the animal units, land base, and nutrients by confined animal facility size class for 1997. The data indicate the contribution that larger operations make to excess nutrients. While medium and small operations can produce a large share of total nutrients (65 percent for N and 61 percent for P across all animals), it is the largest operations that generate the largest shares of nutrients in excess of crop needs. For example, 48 percent of excess nitrogen is generated by the 2 percent of farms that contain more than 1000 animal units, and 52 percent of the excess phosphorus. Sixty percent of total recoverable nitrogen and 70 percent of total recoverable phosphorus from all confined animal farms is in excess of on-farm needs.

Figure 1 summarizes these findings to show that the contribution to excess nutrients varies by animal type. Of the nitrogen that is in excess on the farm, 64 percent is from poultry operations. Of the phosphorus that is in excess on the farm, 52 percent is from poultry. The poultry sector produces the most total nutrients of any sector, and is generally characterized by small amounts of land available for the spreading of manure. As seen in Table 1, this is true across all size classes.

While hogs are not the largest contributors of excess nutrients at the national level, it is the recent concentration in this industry that has raised concerns about the environmental consequences of large animal feeding operations generally. Between 1982 and 1997 the

Table 1. Animal units, land base, and nutrients by size class and animal type, total for the United States in 1997.

Animal type Item and units	Farm class size by animal unit <300	300 - 1000	>1000	Total
Feedlot beef				
Animal units (1000)	1,221	635	7,463	9,318
Land base (1000 hectares)	9,280	600	380	10,260
Recoverable N (tonnes)	23,172	12,056	141,670	176,898
Excess N (tonnes)	6,200	2,188	118,949	127,337
Recoverable P (tonnes)	15,096	7,854	92,295	115,245
Excess P (tonnes)	6,255	2,778	87,122	96,155
Dairy				
Animal units (1000)	5,927	1,836	2,135	9,899
Land base (1000 hectares)	9,668	1,137	334	11,139
Recoverable N (tonnes)	172,719	53,494	62,217	288,430
Excess N (tonne)	11,934	13,876	36,335	62,145
Recoverable P (tonnes)	66,276	20,526	23,874	110,676
Excess P (tonnes)	9,526	8,711	19,889	38,126
Swine				
Animal units (1000)	3,268	2,113	2,852	8,233
Land base (1000 hectares)	9,641	1,022	229	10,892
Recoverable N (tonnes)	49,713	32,602	42,039	124,354
Excess N (tonnes)	13,322	16,530	33,155	63,007
Recoverable P (tonnes)	50,168	32,851	42,571	125,590
Excess P (tonnes)	17,156	23,040	39,830	80,026
Poultry				
Animal units (1000)	2,635	1,651	1,833	6,118
Land base (1000 hectares)	1,540	267	83	1,890
Recoverable N (tonnes)	259,476	125,602	138,004	523,082
Excess N (tonnes)	204,424	105,046	129,411	438,881
Recoverable P (tonnes)	112,876	65,359	73,063	251,298
Excess P (tonnes)	95,505	61,451	72,166	229,122
Total over all types†				
Animal units (1000)	12,717	6,387	14,463	33,568
Land base (1000 hectares)	25,480	3,095	1,073	29,648
Recoverable N (tonnes)	494,316	228,335	390,112	1,112,763
Excess N (tonnes)	216,528	132,708	317,193	666,429
Recoverable P (tonnes)	238,140	128,798	235,873	602,811
Excess P (tonnes)	109,720	90,973	218,838	419,531

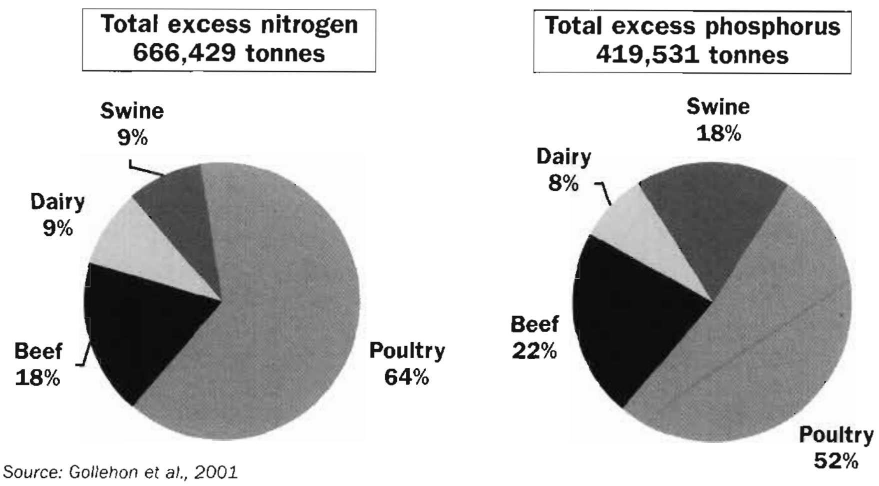
Source: Gollehon et al., 2001.

†Columns are not additive across animal types, since farms may have more than one type.

number of hogs raised in confinement increased by 574 percent, the highest rate of increase of all animal types (Kellogg et al., 2000). By 1997 about nine percent of total excess nitrogen and 18 percent of total excess phosphorus, nationally, were from swine (Figure 1). Hogs were selected for closer examination of manure management practices because of the availability of a survey. The findings are indicative of other animal types raised in confinement as well.

Nutrient management planning and swine farms. Implementation of nutrient management plans will have a major impact on swine operations, whether there is adequate spreadable land or not. Using data from the 1998 Hog Agricultural Resource Management Survey (ARMS) (USDA-ERS, 2000b), we examined the adequacy of current land used for manure application with regards to meeting the proposed nutrient management goals of EPA and USDA. The ARMS survey obtained more than 1,600 responses from 22 states. The survey target population was

Figure 1
Excess nitrogen and phosphorus by animal type.



Source: Gollehon et al., 2001

limited to farms with 25 or more hogs on the operation at any time during the year. The survey sample represents about 95 percent of the U.S. hog inventory in 1998. We grouped data into five multi-state regions: Eastern Cornbelt (IL, IN, MI, OH, WI); Western Cornbelt (IA, KS, MN, MO, NE, SD); Mid-Atlantic (NC, SC, VA); South (AL, AR, GA, KY, TN); and West (CO, OK, UT). We looked at two size classes: combined small and medium-sized operations of < 1000 AU (hereafter called "small") and large operations of > 1000 AU (hereafter called "large").

Data collected by the survey include number of animals, animal types (feeder pigs, market hogs, breeder sows), area of crop and pastureland on the farm, area of land used for spreading, crops grown, crop yields, manure storage system, and whether manure was incorporated or surface applied. We estimated the recoverable nutrients in the manure generated by each farm and the assimilative capacity for the cropland operated by the operation, using the same procedures applied to the Census data, as reported in Kellogg et al., but using data from the ARMS survey on reported crop yields. Nutrient requirements were based on crop uptake and removal for that crop yield. The same 24 crops considered in the Census evaluation were assumed to be suitable for receiving manure. For example, vegetables were not included among available cropland. This assumption may overstate the over application of manure nutrients to the extent that manure can be applied to these crops under certain conditions. Soybeans were not considered suitable for application under a nitrogen-based nutrient management plan (but acceptable under a phosphorus-based plan). Again, this assumption might overstate the over application of manure nitrogen to the extent that a nutrient management plan could allow some small amounts of N to be applied to soybeans. Adjustments for nutrient losses in collection, storage, and transport were based on the technologies reported in the survey and on loss coefficients reported in the literature (Fleming et al., 1998; Kellogg et al., 2000). For example, the nutrient concentrations in lagoon liquids that are applied to fields do not include manure nutrients contained in the sludge that settles on the bottom. To account for volatilization in the field, total N in manure was reduced 5 percent if manure was incorporated, and 30 percent if it was surface applied (Fleming et al., 1998).

We estimated the amount of cropland that would be needed to meet a nitrogen-based (N-based) nutrient management plan and phosphorus-based (P-based) nutrient management plan after all nutrient losses in collection, storage, and application were taken into account. For those farms reporting no cropland as part of the operation, land needs were based on regional average nutrient removals. Average removal for nitrogen for the Eastern Cornbelt, Western Cornbelt, Mid-Atlantic, South, and West regions in kilograms per hectare are, respectively, 119.5, 134.4, 111.1, 92.8, and 63.9 (106.6, 119.9, 99.1, 82.8, and 57.0 pounds per acre). Average removal for phosphate in kilograms per hectare for the regions are, respectively, 46.6, 50.0, 39.9, 36.3, and 40.5 (41.6, 44.6, 35.6, 32.4, and 36.1 pounds per acre).

Results and Discussion

Many farms applying on too little land. We assumed that all hog manure was applied to land operated by the operation. Hog manure has a high moisture content and is costly to transport, so it is not likely to move far from the confinement buildings without any regulatory requirements. Findings from the survey indicate that about 37 percent of confined hog farms with less than 1000 animal unit (AU) were applying manure on an adequate amount of cropland to meet the nutrient needs of an N-based plan, nationally (Table 2). For larger farms of greater than 1000 AU, however, only about three percent were estimated to be applying manure nitrogen at agronomic rates (Figure 2). The percentage of smaller farms meeting the needs of an N-based plan were highest in the two Cornbelt regions, and lowest in the Mid-Atlantic region. The percentage of larger farms meeting an N-based plan was highest in the South region.

Fewer farms are spreading manure on cropland at rates consistent with a P-based plan. Animal manure contains more phosphorus than nitrogen relative to plant needs, meaning that less manure can be spread on a given area to meet a phosphorus limit than a nitrogen limit (Mullins, 2000). Therefore, with a given amount of manure, more land would be required for spreading under a phosphorus limit than a nitrogen limit. Only about 16 percent of farms with less than 1000 AU indicated that they are spreading on a land base consistent with a P-based limit. This percentage drops to about one percent for operations with more than 1000 AU. This result implies that requiring a P-based plan would require management changes on many more farms than an N-based plan would.

An indication that hog farms are not fully treating manure as a nutrient source is that many of the farms over-applying manure were not using all their spreadable land. There was a large difference between the amount of land farms indicated they were applying manure to and the amount of spreadable land actually available on the farm (Figure 2). If all suitable land were used for spreading, almost 74 percent of the smaller farms could meet the needs of an N-based plan, and about 62 percent could meet the needs of a P-based plan (Table 2). However, for larger operations, only about 20 percent could meet the needs of an N-based plan, and

Table 2. Percentage of hog farms meeting nitrogen (N)-based and phosphorus (P)-based plans, by region and size, 1998.

Region	Number of farms	Farms meeting N-based plan	Farms meeting P-based plan	Farms with adequate land for N-based plan	Farms with adequate land for P-based plan
		Percent			
Eastern Cornbelt					
<1000 AU	9,415	37.2	15.2	72.7	65.3
>1000 AU	357	3.1	0	56.8	37.5
Western Cornbelt					
<1000 AU	19,356	39.9	17.1	79.1	71.9
>1000 AU	1,254	3.2	3.2	24.8	22.3
Mid-Atlantic					
<1000 AU	1,426	10.0	2.9	25.3	20.4
>1000 AU	1,113	2.6	0	7.7	2.8
South					
<1000 AU	1,844	30.4	16.2	72.1	62.9
>1000 AU	84	11.2	0	15.2	0
West					
<1000 AU	491	15.0	6.7	34.0	30.0
>1000 AU	184	0	0	0	0
Nation					
<1000 AU	32,532	36.9	15.7	73.8	66.6
>1000 AU	2,992	3.0	1.3	20.4	14.9

Source of data: 1998 Hog Agricultural Resource Management Survey.

Eastern Cornbelt includes IL, IN, MI, OH, WI

Western Cornbelt includes IA, KS, MN, MO, NE, SD

Mid-Atlantic includes NC, SC, VA

South includes AL, AR, GA, KY, TN

West includes CO, OK, UT

15 percent of a P-based plan, if all their available land were fully utilized. Larger farms in the Mid-Atlantic, South, and West were particularly deficient in adequate land for application of manure at agronomic rates. This gives an indication of the problems that a mandatory nutrient management plan might pose for larger operations.

Some operations might address their manure management problems by selling it, giving it to neighbors, or otherwise moving it off the farm. Nationally, about 20 percent of large and small operations move some manure off the operation (the percentage of a farm's manure that is moved could not be calculated from survey data) (Table 3). Farms in the Mid-Atlantic were less likely to remove manure from the farm than in any other region.

When land application is being used primarily as a means of disposal for manure, there is further evidence that less than 20 percent of small farms test their manure for its nitrogen or phosphorus content. A much higher percentage of larger farms test their manure (72 to 73 percent). However, based on the small percentage of large farms spreading on a land base consistent with an N- or P-based plan, the information from testing is apparently not being fully used. It is interesting to note that manure nutrient testing was most widespread in the Mid-Atlantic, where most farms do not move manure off the farms and are apparently spreading on an inadequate amount of land.

It is important to note that the estimate of land necessary to meet a P-based plan takes into account the reported use of phytase, an enzyme that can be added to the feed of poultry and swine. Phytase enables non-ruminants to better utilize phosphorus in grain, thus reducing the need to add the mineral di-calcium phosphate to feed. The addition of the phytase to poultry and hog feed can reduce the phosphorus content of manure by up to 45 percent (Harper, 2000). Phytase is most often used by larger operations, but less than a quarter of these operations in any one region used it in 1998 (Table 3). Nationally, only 8 percent of smaller farms and 14 percent of large farms used phytase-treated feed. We consider an increased use of phytase in the next section.

Farms need more land for utilizing manure. We used the ARMS data to characterize the "average" farm in each size class in each region to estimate the amount of additional land it would need to meet N- and P- based nutrient management plans. The data show that the average operation in each size class is spreading on a smaller land area than would be allowed under an N-based plan (Figure 2). The discrepancy between land area being used and land area needed is smallest in the Western Cornbelt region. The smaller operations use almost enough land to meet the needs of a nitrogen-based plan. The larger operations in this region must increase the amount of land receiving manure by a factor of nearly three.

In the Mid-Atlantic the deficiency in spreadable land is much greater (Figure 2). Large operations must increase the land area they utilize by a factor of 9. Smaller operations must increase the amount of land they use by a factor of 5. In general, large operations must increase the amount of spreadable land by a larger percentage than small operations, due to smaller operations generally having more land per animal unit (Gollehon et al., 2001).

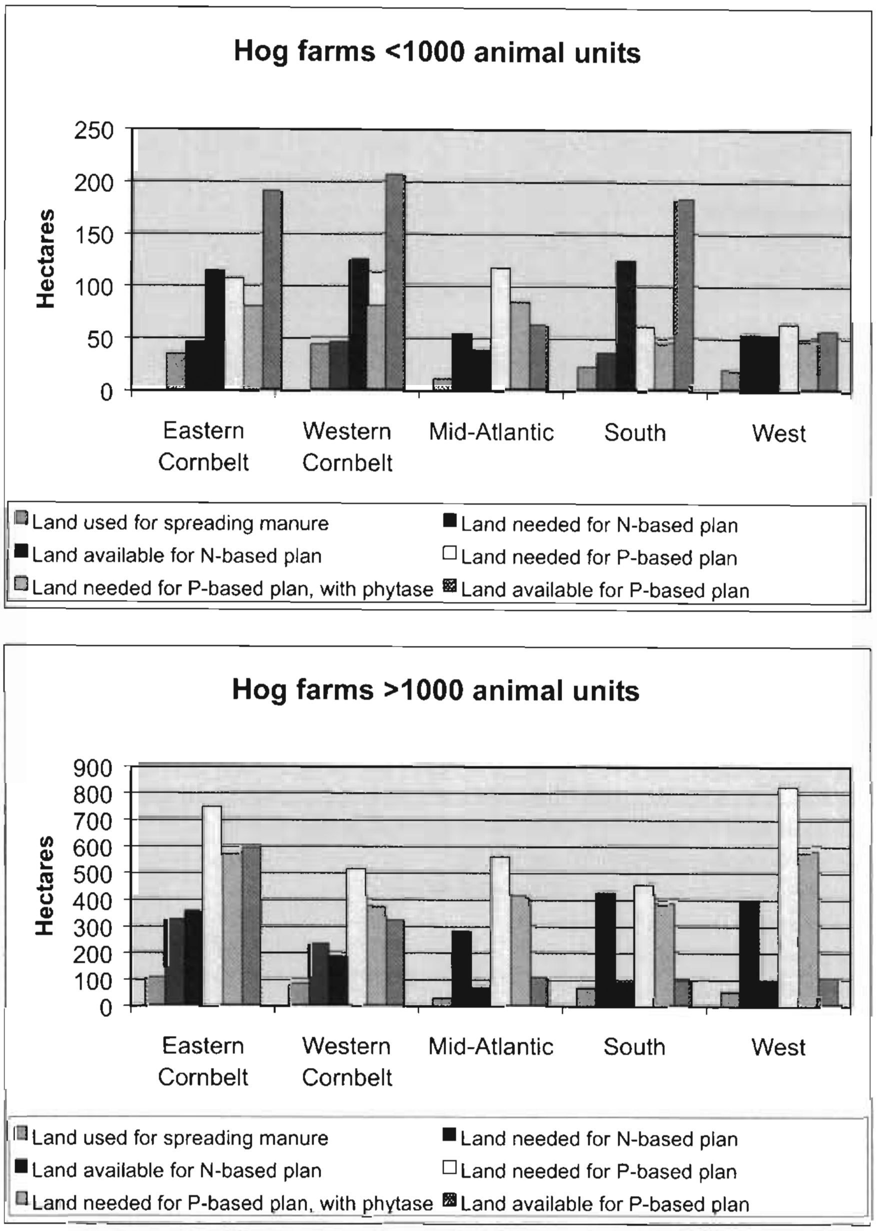
If a phosphorus based nutrient plan is required, individual producers will have to greatly increase the amount of land they use for spreading. None of the average farms are currently spreading on enough land to meet a P-based plan. In the Western Cornbelt, the average operation with more than 1000 animal units would have to increase the amount of land for spreading by a factor of 6. Smaller operations would have to increase their spreadable land by a factor of 2.5. In the Mid-Atlantic region the amount of land used for spreading by the largest operations would have to increase by a factor of 18. Even small operations, which tend to have more land per animal unit, would have to increase the amount of land they are spreading on by a factor of over 10.

Utilizing their own land for land application of manure would pose fewer problems to farmers than finding willing landowners to accept manure. As seen in Figure 2, farms on average do not utilize all their spreadable land for land application of manure. If operations spread animal manure on all their available land, the average farm with less than 1000 AU would have adequate or nearly adequate land for an N-based plan in all regions but the Mid-Atlantic.

The average large operation in the Eastern Cornbelt operates enough spreadable land to meet the needs of an N-based plan. The average large operation in the Western Cornbelt would need to find an additional 47 hectares (116 acres) for spreading (an increase of about 25 percent). In the remaining regions, a sizable deficit in spreadable land would have to be made up in order to meet the requirements of an N-based plan. In the Mid-Atlantic, land for spreading would have to increase by a factor of 3 beyond what is currently owned. In the South and West regions available land would have to increase by a factor of 4.

Figure 2

Estimated land area being used for spreading and area needed to meet nutrient management plan by hog farms, by region and size, 1998.



Eastern Cornbelt includes IL, IN, MI, OH, WI; Western Cornbelt includes IA, KS, MN, MO, NE, SD; Mid-Atlantic includes NC, SC, VA; South includes AL, AR, GA, KY, TN; West includes CO, OK, UT

Source of data: 1998 Hog Agricultural Resource

The average farms with less than 1000 AU in the Eastern Cornbelt, Western Cornbelt, and South have adequate cropland under their control to meet the needs of a P-based plan. For average farms of less than 1000 AU in the Mid-Atlantic, cropland holdings would have to increase by a factor of over three to meet the needs of a P-based plan.

None of the average large farms have

Table 3. Manure nutrient testing, phytase use, and manure removal by hog farms, by region and size, 1998.

Region	Test for N content of manure	Test for P content of manure	Use phytase in feed	Move manure off the farm
	Percent			
Eastern Cornbelt				
<1000 AU	15.5	16.4	10.9	18.9
>1000 AU	44.8	44.8	20.1	22.4
Western Cornbelt				
<1000 AU	15.7	15.1	4.1	21.2
>1000 AU	61.2	61.2	16.1	42.1
Mid-Atlantic				
<1000 AU	77.2	74.4	9.5	3.8
>1000 AU	94.1	89.8	13.3	1.1
South				
<1000 AU	22.0	21.7	6.9	18.6
>1000 AU	89.5	89.5	22.7	7.9
West				
<1000 AU	43.7	43.7	12.8	45.6
>1000 AU	74.9	74.0	0	0
Nation				
<1000 AU	19.2	18.9	6.6	20.0
>1000 AU	73.1	71.5	14.7	20.9

Source of data: 1998 Hog Agricultural Resource Management Survey.

Eastern Cornbelt includes IL, IN, MI, OH, WI

Western Cornbelt includes IA, KS, MN, MO, NE, SD

Mid-Atlantic includes NC, SC, VA

South includes AL, AR, GA, KY, TN

West includes CO, OK, UT

enough land to meet a P-based nutrient management plan. The discrepancy is least in the Eastern Cornbelt, where a 27 percent increase in land would be needed. In the Mid-Atlantic, the average large farm would have to increase suitable land by a factor of five. In the West, the increase would have to be by a factor of 8.

We examined the impact more widespread phytase use might have by estimating the reduction in land needed for spreading under a P-based nutrient management plan if phytase was used by all operations (assuming a 30 percent reduction in manure P). In this case, the need for additional land beyond what the operations already own would be reduced by between 16 and 28 percent, depending on size and region (Figure 2). While the need for land is reduced, sizable amounts would still be needed to meet a P-based plan in most regions. Only in the Eastern Cornbelt would the average large farm have enough land to meet a P-based plan.

Regional impacts of concentration. Excess on-farm nutrients are not an issue if they are applied to adjacent lands at appropriate rates or used for other purposes, such as composting, energy production, or fertilizer production. The ARMS data indicate that many hog operations will need to find large amounts of additional land suitable for spreading if they are required or choose to follow a nutrient management plan and alternative disposal methods are not available. If animals are concentrated geographically, it may be difficult to find enough land within an economical distance to handle animal manure at agronomic rates. Confined hog operations might be faced with the prospect of competing with other each other, as well as with confined dairy, beef, and poultry operations, for spreadable land.

There are many factors that can limit the amount of land available for spreading, including land cover, depth to water table, location of streams and wells, local regulations, transportation costs, and landowner preferences. Gollehon et al. used data from the 1997 Census of Agriculture to show which counties have sufficient cropland to use all the excess nutrients available from all confined livestock operations within those counties. Manure nutrient production from confined livestock in a county was compared to total county nutrient needs to help identify areas where manure nutrients could supply a major portion of the county's total crop nutrient needs. Only crops suitable for receiving manure were considered in estimating potential nutrient uptake. Factors not taken into consideration included depth to water table, location of streams and wells, regulations, or landowner preferences. Comparing manure nutrient production and crop nutrient needs at the county level assumes that movement beyond a county is economically infeasible.

The excess nutrient values calculated for a county represent a consistent estimate of the manure nutrients that would need to be transported off farms in order to reduce the potential for nutrient loss to the environment. Regional excess is underestimated because small livestock farms are not included and commercial fertilizer use is not accounted for. Partially offsetting the underestimation is the possibility of applying manure to nonagricultural land. This option was not considered because manure application is often incompatible with multiple uses of land without extensive processing.

The data show that most counties have adequate assimilative capacity to handle the manure generated by all animal types raised on confined facilities in those counties through land application (Figures 3 and 4). However, in 155 counties (5 percent), the estimated manure nitrogen produced on confined livestock and poultry farms could provide at least half the entire county's total nitrogen need. This includes 68 counties where manure nitrogen levels exceed the assimilative capacity of all the county's crop and pastureland. These counties are located primarily in North Carolina, northern

Georgia, Alabama, central Mississippi, western Arkansas, and California. Hog operations located in any of these will have a difficult time finding the large amounts of additional spreadable land as indicated in Figure 2.

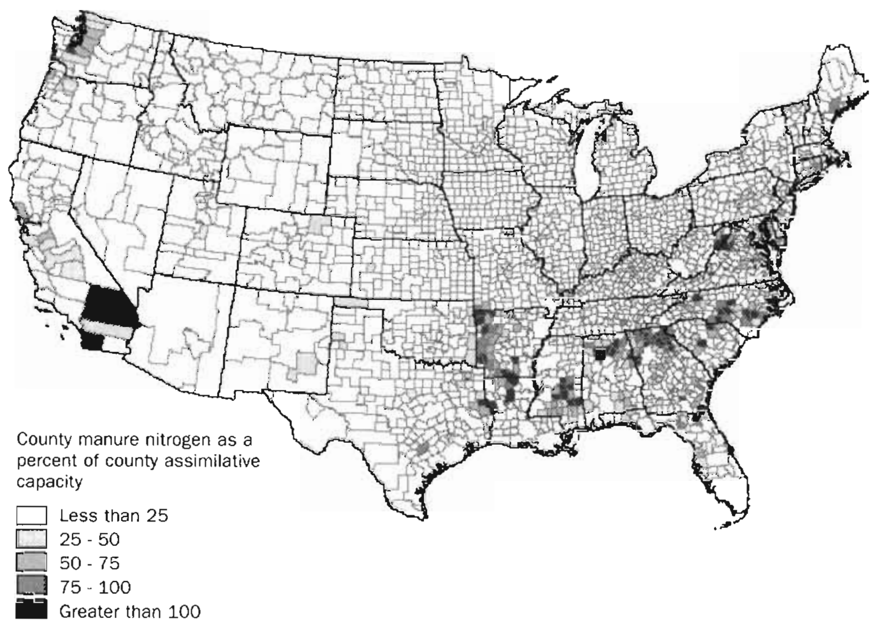
Many more counties have county-level excesses of phosphorus. In 337 counties (10 percent), the estimated manure phosphorus produced on all confined livestock and poultry farms could provide at least half the entire county's total phosphorus need. This includes 152 counties where manure phosphorus levels exceed the assimilative capacity of all the county's crop and pastureland. These areas are located primarily in western Virginia, Delmarva Peninsula, eastern North Carolina, northern Georgia and Alabama, Central Mississippi, Western Arkansas, and Southern California. Again, hog operations located in these counties will have a difficult time finding the large amounts of spreadable land necessary to assimilate the phosphorus they generate.

Areas with a regional excess of manure nutrients have the greatest need for off-farm alternatives to land application, such as treatment to reduce the volume (composting) or industrial processes that can use manure as a feedstock (such as the plants located in eastern Maryland and Rockingham County, Virginia). It is these areas that will probably have the greatest difficulty in meeting land application requirements in regulations proposed by the EPA and comprehensive nutrient management plans advocated by USDA.

Even if land is available for spreading in a county, not all landowners will be willing to take animal manure. There are several drawbacks to land application of manure that could discourage greater use on cropland. These include uncertainty associated with nutrient availability, high transportation and handling costs relative to commercial fertilizer, soil compaction due to heavy tanker traffic, the introduction of weed seeds, and public perception regarding odor issues (Risse et al., 2001). Cropping practices data over 1990 through1997 indicate that manure was applied to relatively little land (USDA, ERS, 2000a). Application to major field crops ranged from 2 to 3 percent of winter wheat to 13 to18 percent of corn (USDA-ERS, 2000a). Low use occurs despite the fact that the manure generated annually in the United States contains 5.8 million tonnes (about 6.4 million tons) of nitrogen (N) and 1.7 million tonnes (1.9 million tons) of phosphorus (P) (Kellogg et al., 2000). This compares with

Figure 3

Excess manure nitrogen as a share of county assimilative capacity, 1997.

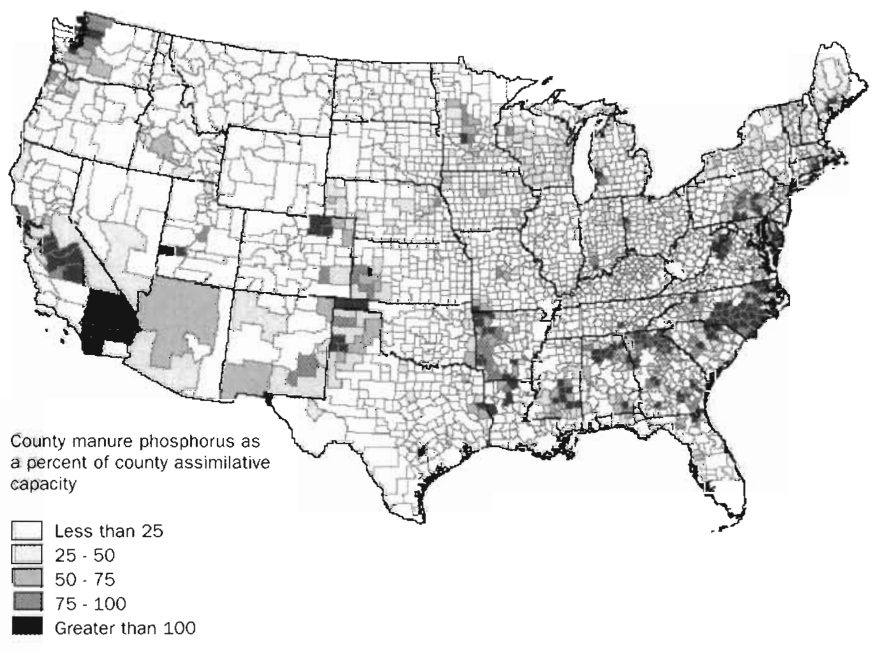


Some counties are combined to meet disclosure criteria.

Source: Economic Research Service, USDA.

Figure 4

Excess manure phosphorus as a share of county assimilative capacity, 1997.



Some counties are combined to meet disclosure criteria.

Source: Economic Research Service, USDA.

10.9 million tonnes (12 million tons) of commercial N and 4.1 million tonnes (4.5 million tons) of commercial P applied by U.S. farmers in 1998 (USDA-ERS, 2000a). Without further analysis one cannot say whether these results reflect the costs of moving manure off the farm or the preferences of the farmers themselves.

Summary and Conclusion

Proposed changes to Clean Water Act regulations pertaining to animal operations would limit manure-application rates on crop and pasture land for those animal feeding operations falling under the regulation. In addition, USDA is promoting the use of comprehensive nutrient management plans as a management practice for all AFOs to reduce the potential for nutrient movement to the environment. These actions culminate in the need for either an increase in the amount of spreadable land operated by the farm, or a large increase in the amount of manure moved beyond the farm operation. This is especially true for nutrient management plans based on achieving a phosphorus goal. Where there is adequate land nearby but landowners are reluctant to use manure, providing transparent information on the benefits and costs of using manure rather than commercial fertilizer as a nutrient source, and on manure management can help assure that cost-effective decisions are made in meeting environmental goals.

In some regions the concentration of animals is such that there may not be adequate land suitable for spreading manure, even if all landowners are willing to use it. Some changes in cropping patterns on livestock farms could be made to increase nutrient uptake. Alternative uses of manure, such as a feedstock or commercial fertilizer, energy production and composting may enable high concentrations of animals to exist on a regional level and still meet clean water regulations. New manure management methods and alternative feed rations might also help. Otherwise, operations in "saturated" counties may have to reconsider livestock numbers or their location.

The results reported in this paper pertain strictly to the need for land for spreading animal manure according to a nutrient management plan. The costs of acquiring land or land services, providing local crop farmers with an incentive to accept manure, or of transporting and applying manure to more land are not addressed in this paper. Obviously, these costs will play a major role in determining how animal operations might choose to deal with future regulations, even if the necessary land is available.

Endnotes

[1]An animal unit is defined as 1,000 pounds live weight. Our definition should not be confused with the Clean Water Act specification of "1,000 animal units." The Clean Water Act specified that a farm producing more than one animal type could be a Concentrated Animal Feeding Operation if the sum of the animals totaled 1,000 animal units. The regulations specified an animal per animal unit conversion only for that purpose and only for slaughter and feeder cattle, mature dairy cows, swine, sheep, and horses. No conversions were specified for any type of poultry. These specifications of animals per animal unit have proven to be confusing because they are not complete and are not based on a common specification.

The number of animals per animal unit are as follows: feedlot beef - 1.14; dairy cows - 0.74; swine for breeding - 2.67; swine for slaughter - 9.09; laying hens and pullets > 3 months - 250; Broilers and pullets < 3 months - 455; turkeys for breeding - 50; turkeys for slaughter - 67 (Gollehon et al., 2001).

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