Chapter 4
ON-FARM EVALUATION OF ADOPTING PHOSPHORUS VERSUS NITROGEN LIMITS FOR MANURE APPLICATION ON U.S. SWINE OPERATIONS

John A. Lory[1], Ph.D., Ray Massey[2], Ph.D., Joe Zulovich[3], Ph. D., P.E., Amy Millmier[3], M.S., E.I.T., John Hoehne[3], M.S., P.E. And Chanda Case[2], M.S.

4.1 INDEX

[1] Dept. of Agronomy, University of Missouri, Columbia, Missouri 65211
[2] Dept. of Agricultural Economics, University of Missouri, Columbia, Missouri 65211
[3] Dept. of Biological Engineering, University of Missouri, Columbia, Missouri 65211

4.2 EXECUTIVE SUMMARY

- A simulation model containing 7 modules (1) an animal production module, 2) a manure storage design module, 3) a manure nutrient generation module, 4) a nutrient management module, 5) a GIS module, 6) a manure application module and 7) an economic simulation of swine production module) was used to estimate the feasibility and impact of proposed EPA CAFO regulations on 31 farms in 5 states.
- Feasibility was defined as either technically feasible using current land application technology or able to be accomplished within a window of fieldwork days appropriate for manure application.
- Farms using tankers to distribute pit slurry were operating near their maximum travel speed and therefore needed to reduce discharge rate or increase swath width to comply with phosphorus limits. Twenty percent of the operations would be unable to attain annual phosphorus application rates even with totally new equipment purchases. Rotational phosphorus limits was their only method to attain compliance.
- PA and IA will have the most difficultly accommodating a phosphorus rule because they predominately use pits, have increases in application time due to over-the-road tanker transportation and grow row crops that limit when manure can be applied prior to planting.
- The average monthly capacity of pits in IA and PA is 7 months. Any regulations against fall applied manure for spring planted crops will severely affect IA and PA.
- In the short run, producers in MO and IA using lagoons are relatively unaffected by a switch to a phosphorus rule as long as they are not required to agitate lagoons. Producers in NC using lagoons will need to access 25% more acres to implement a phosphorus limit. The predominate use of irrigation technology and the geography of NC could make this difficult. (Note: short run analysis does not take into account cleaning and closing lagoons that have filled with sludge).
- The estimated average cost of land application of manure was $.006/gallon for traveling guns and dragline technologies, $.001/gallon for center pivots, $.003/gallon for stationary sprinklers, $.007/gallon for truck-mounted tankers and $.012/gallon for tractor pulled tankers.
- Independent swine producers currently spend an average of 2% of their gross revenue on land application of manure (does not include storage structure costs); contract producers spend an average of 10% of their gross revenue on manure management.
- Our analysis estimates 6 of the remaining 30 farmers (one farm could not comply) capable of applying manure under a phosphorus rule (20%) would have a greater than 5% increase in the cost:sales ratio. All are contract producers. Five are in PA and one is in IA. All apply pit slurry with a tanker. Forty six percent of contract producers are in the stress category.
- We predict that the EPA's economic assessment of farms in the moderate to stress categories is underestimated. Table 10-6 of the Preamble (Federal Register, p 3090) reports that the EPA estimates that 20% of the hog producers will be in the moderate to stress categories. Their estimate of 20% includes the cost of attaining zero discharge. Our estimate of 20% considers only the cost of implementing a rotational phosphorus limit.

4.3 INTRODUCTION

This chapter seeks to follow the impact of implementing a phosphorus limit through the entire swine production system.

Correctly assessing any regulatory change requires that the impact on production and financial measures of the business be understood. Second, the regulations need to be deemed technically feasible. Third, the rules must be financially feasible for the businesses subject to the rules.

In order to understand the system in which regulations would be implemented, we chose to model the impacts of regulations on real farms rather than hypothetical farms. We went to five states and extensively interviewed over 50 farms. Of those we were able to model 31 farms to determine what they were presently doing for manure management and what the impact of regulations would be on these specific farms.

The results enabled us to evaluate the impact of proposed regulation on land availability for manure application and the differences between farms in different geographic regions and with different business structures.

Technical feasibility requires a thorough understanding of the system within which the rules will be implemented. Environmental regulations on confined animal feeding operations have impact on animal production, engineering designs, cropping systems and financial performance.

We looked at the impact of application rate changes on travel speed, discharge rate and swath width to determine if the farmer could implement the rule with little or no monetary outlay. When current equipment was not capable of implementing a change, we sought to identify and acquire equipment that could accomplish with the application requirements imposed by the proposed regulation. On several occasions it was deemed that no capable equipment currently existed, or that the availability of the equipment was so limited that purchase and operation was not likely to occur. The proposed rule created a change that affected the whole system and not an portion of the system.

Environmental regulations affect the financial performance of businesses seeking to comply with them. Financial performance is composed of profitability, liquidity and solvency. Changes in profitability as measured by return on assets were determined for the different systems. Sales as a percent of gross revenue were evaluated because this was the primary measure used by the USEPA to determine financial impact. We also looked at (but had difficulty reporting) the impact on liquidity by observing the impact of equipment purchases and annual operating cost increases on cash flow.

The result of our analysis of the sample of real farms is that an annual phosphorus limit is unnecessary to achieve the environmental goals of the USEPA. An annual phosphorous limit is either infeasible, or more expensive when feasible, than a rotational phosphorus limit. We also find that regional and business organization differences are significant in understanding the impact of the proposed rule.

4.4 Methods and Materials

Farm visits were conducted to gather data on current manure management on farms in IA, OK, MO, NC and PA. These states were chosen to represent the four major pork production regions in the US as defined by EPA. Appendix A describes the farms, their type of manure storage and land application technology. The survey collected information about the location of the farm; the number, production phase and size of swine on the farm; the amount of water use in the buildings; description of the manure handling and storage system; estimates of annual manure volume; nitrogen, phosphorus and potassium concentration in the ration; manure test results; description of crop rotations including yield goals; location of fields receiving manure, streams, wells and other sensitive areas near the land application areas; equipment used for manure application and estimates of the time required for manure application. Farmers were also asked for soil test phosphorus levels for each field. All information was not available on all the farms.

4.4.1 Simulation Model

The collected data was used to develop the input and to validate the results of a simulation model used to estimate time requirements, land requirements and economic ramifications of adopting either an annual phosphorus-based application strategy required by the proposed EPA rule or a phosphorus rotation strategy. The mechanistic simulation model used contains the following seven modules: 1) a swine production module, 2) a manure storage design module, 3) a manure nutrient generation module, 4) a nutrient management module, 5) a GIS module, 6) a manure application module and 7) an economic simulation of swine production module (Massey, et al., 2000).

The animal production model predicts the number of animals at each phase of production based on specific production characteristics including weekly, bi-weekly, or monthly farrowing capacity, farrowing rate, pigs per litter, days pigs are in the nursery, weight leaving the nursery, wean to finish average daily gain, and market weight. Typically, actual animal numbers in each phase of production were clearly reported by the operator and were used in this analysis instead of the predicted animal numbers using the animal production model.

The storage design model estimated volume of manure or effluent pumped annually from the manure storage facility based on county weather data, animal numbers and the geometry and type of the manure storage facility. Nutrients excreted by the animals were estimated in the nutrient generation model based on the quantity of nutrients fed the animals and efficiency of the nutrient retention estimated from a literature review. Typically, we used model estimates of mean volume of manure pumped annually and the farmer manure test result to estimate nutrient generation. Results of the predicted manure volume and nutrient concentration were compared with manure test results and farmer estimates of manure volume as a check on accuracy of volume and manure nutrient concentration estimates used in the analysis. In some cases farmer manure test results were rejected when low manure nutrient concentrations implied improbably high nutrient efficiencies based on model results. Feed-based estimates of nutrient content of the manure were used when no manure test data was available.

Farmers were asked to identify on a map all fields on their farm and on rented farms. A geographical information system (GIS) was used to map fields, calculate field size, determine acres suitable for manure application (field size minus water quality set backs), and measure the distance the manure must be transported from storage to field. The total number of acres, the acres in crop production and the crop acres suitable for manure application were determined for each farm. Farmers were also asked to identify other farms where they currently apply manure and to identify other fields and farms where they anticipated they could apply manure if they needed more land. Neighbors' farms that were designated as potentially receiving manure were also mapped.

Fertilizer need for each field for each year of a 4-year crop rotation was determined based on farmer reported yield goal. Nitrogen need of non-legume crops was calculated based on the state-specific fertilizer recommendations. Phosphorus and potassium fertilizer need of all crops and nitrogen fertilizer rate for legumes was calculated based on crop removal capacity of the crops (Table 4-1).

Fields were prioritized for manure application based on proximity to storage (tanker technology and pivot irrigation) or to minimize additional piping requirements to the next field (irrigation and dragline technology). The fields within a similar distance to storage were further ordered based on nitrogen fertilizer need (e.g. corn preferred to soybean because corn requires fertilizer N whereas soybean has no fertilizer N requirement).

A computer program was used to calculate the application rate and distribute manure to the ordered fields until all manure was distributed. Application rates based on nitrogen need were based on the plant available nitrogen content of the manure. Manure plant available nitrogen (PAN) was estimated by assuming 35% of the total nitrogen is organic nitrogen in slurry pits; 20% in lagoons. Application rates based on phosphorus were based on the total phosphorus content of the manure. Manure phosphorus and potassium was assumed to be 100% equivalent to other phosphorus and potassium fertilizer sources.

Time required to distribute manure was calculated using a mechanistic budgeting approach. Manure distribution time is composed of setup time, transport time and land application time. Farmer supplied data was used, where available, to estimate time parameters such as travel speed and pipe layout time. Where no farmer-supplied data were available, a time motion study performed at the University of Missouri in 1999 (unpublished data) was used to estimate time parameters.

Storage setup time was the positioning of any pumps and pipes used in manure application. Examples of storage setup activities would be setting up pumps for agitating and unloading the storage. A 2-hour setup time was assumed for each storage. If the storage was agitated prior to pumping, agitation time was added to setup time.

Table 4-1. Nutrients removed in the harvested portion of selected crop.

Crop	Yield unit	N lbs/unit	P_2O_5 lbs/unit	$N:P_2O_5$ ratio	K_2O lbs/unit
Corn grain	bushels	0.9	0.4	2.3	0.3
Corn silage	tons	8.4	3.8	2.2	8.9
Soybean	bushels	3.4	0.8	4.3	1.4
Wheat	bushels	1.3	0.7	1.9	0.4
Bermuda grass hay	tons	49	11	4.5	42
Big bluestem hay	tons	20	11	1.8	26
Tall Fescue hay	tons	39	14	2.8	53
Alfalfa hay	tons	50	12	4.2	50

Note: Values are reported as nitrogen (N), phosphate (P_2O_5) and potash (K_2O).
Sources:
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Atlas of nutritional data on US and Canadian Feeds. 1971. National Acad. of Sciences, Washington, DC.
Griffith, W.K. and L.S. Murphy. 1996.
Macronutrients in Forage Production. In (R.E. Joost and C.A. Roberts eds.) Nutrient Cycling in Forage Systems. Proc. Of a conference held March 7-8, 1996. Columbia, MO.
PPI, Manhattan, KS

Transportation time for tanker technology is a function of the distance from storage to field. Our study used a road travel speed of 10 miles per hour when the tank is pulled by a tractor and 20 miles per hour when mounted on a truck. Within field travel speed (travel from the road to the point within the field where manure is applied) was set at 5 miles per hour.

The time required for setup of distribution pipes for technologies such as irrigation and dragline was viewed as transportation time. Lay down and pickup time for aluminum pipe was assumed to require three persons and was estimated to take 11.6 hours per mile of pipe lain. Lay down and pickup time for flexible hose was assumed to require two persons and was estimated to take two hours per mile. In traveling gun systems, an additional setup time of one hour per pull was included in traveling gun transportation time to move the irrigation to the next pull lane and to extend the traveling gun to the end of the pull lane. In dragline systems, an additional setup time of 30 minutes was added for each additional pull from a pivot point for moving the tractor and hose from the end of the first pull to the beginning of the second.

Application time is a function of discharge rate (gallons/minute) from the land application equipment. The manure-pumping rate was assumed at the highest mechanically attainable discharge rate within the field speed range of the land application equipment. The model was constrained by a permissible range of field speeds for each piece of equipment. For tankers and pivots, swath width was held constant; for traveling guns, swath width occasionally decreased with discharge rate.

Lowering discharge rate often requires equipment modifications such as installing a pinch valves and/or manifold distribution systems. If adjustments in travel speed and discharge rate were insufficient to meet an application rate the application rate was considered not to be feasible for that farm.

Changing application rate (gallons/acre) directly affects the discharge rate. Application time changed when the constrained application rate caused a change in setting on equipment used. The producer's choice of discharge rate, application swath width and field travel speed establishes the application rate. Our analysis assumed that the producer would choose to use their current equipment complement and considered swath width as a pre-determined variable. Most producers modeled currently operate in the upper range of the attainable field speed (Of 14 tankers modeled in our study, the average speed was 4.4 miles per hour. See table 3-4).

Feasibility of calculated application rates was assessed for equipment reported for manure application use. Application rate was met by maximizing discharge rate for the specific piece of equipment. Travel speed was used to adjust equipment application rate. If more adjustment were required to attain the desired application rate, discharge rate would be lowered. Lowering discharge rate often requires equipment modifications such as installing a flow reducer. For tankers and pivots, swath width was held constant; for traveling guns, swath width varies with discharge rate. If adjustments in travel speed and discharge rate were insufficient to meet an application rate, the application rate was considered not feasible for that farm.

Depreciation of power equipment is a function of age and annual hours used. Depreciation of non-power equipment is considered a function of age only. Depreciation was estimated using the remaining value coefficients estimated by Cross et al. [, 1995 #293]. Remaining value was input into other cost estimates of interest (7%/year), taxes and insurance (2%/year), and repair. Standard cost estimation techniques were used.

A labor rate of $10/hour was charged regardless of the season when manure is distributed or the total number of hours needed for manure distribution. Fuel cost was set at $1.00 per gallon.

If the producer used a custom manure applicator rather than personally owned and operated equipment, an hourly custom rate was charged to the number of hours estimated by the model. The hourly rate charged was reported by the producer and varied from producer to producer and by geographic region.

4.4.2 Fieldwork days

The USDA Ag Statistics Services in each state track fieldwork days per week and progress of planting and harvest. Table 4-2 presents the fieldwork hours for OK, IA, MO, and PA (USDA). These reports were used to estimate the number of hours available for manure distribution. Reported field work days were divided into the following categories: 1) pre-planting season, 2) planting season, 3) growing season, 4) harvest season and 5) post-harvest season.

Table 4.2. Fieldwork hours for different cropping seasons

	MO		OK			PA		IA	
Cropping Season	Corn	Soybean	Corn	Soybean	Wheat	Corn	Soybean	Corn	Soybean
Pre-planting	74	225	813	1062	728	239	361	173	300
Planting	275	181	181	447	261	198	278	174	165
Growing Season	1183	1306	1202	813	1347	1319	1117	1407	1232
Harvest	398	219	327	321	246	318	221	246	198
Post-harvest	106	106	688	568	n/a	46	141	207	325

Source: USDA State Ag Statistic Services

When zero or one out of the last five years had no suitable fieldwork days, no fields were assumed suitable for working. MO, PA and IA have weeks with no reported fieldwork days. OK reports suitable fieldwork days every week of the year. When at least two of the last five years have reported fieldwork days, these fieldwork days are averaged and multiplied by the number of hours of sunlight for that week to determine available fieldwork hours for the respective season.

Pre-planting season reports the number of fieldwork hours after the ground thaws and before the “most active planting season” begins. Most active planting season is shorter than usual planting season, allowing a longer period for pre-plant manure application. Pre-planting season is the time most producers can perform activities such as manure distribution, tillage, fertilizer application and seedbed preparation. All injected or incorporated manure application must occur during this season in order to not interfere with crop growth and to utilize the fertilizer value of the manure.

Planting season fieldwork hours are the number of hours available for planting during the “most active planting season.” Usual planting occurs before and after this time but was included in the pre-planting and growing seasons to make conservative time limitation estimates. During the most active planting season the producer is assumed to be planting and have no time for other field activities.

Growing season is the time between planting and harvesting. For most crops, only irrigation of manure effluent can be done at this time. Surface application using tankers can be done in limited situations. For hay crops, manure distribution was assumed possible as surface application of manure for one week after each hay cutting. Harvest season fieldwork hours are the number of hours available for harvest during the "most active harvest season." Usual harvest fieldwork hours occur before and after the "most active" harvest season time. The harvest fieldwork hours occurring before and after the "most active harvest season" were included in the growing and post-harvest seasons to make conservative time limitation estimates. During the harvest season, the producer is assumed to be harvesting and have no time for other field activities.

Post harvest season is the number of hours available after harvest season and before the ground freezes. Field activities such as tillage and fertilizer application can be performed during this season but are discouraged in order to reduce soil and nutrient losses. No manure application was assumed during this season.

The fieldwork time estimates give an impression of the feasibility of manure application during appropriate periods. For example, a typical Iowa farm growing corn and soybeans would be expected to have 173 hours prior to planting corn for manure application. Prior to soybean planting, the farmer has an additional 127 hours available. However, corn planting will be the priority activity during that time and little time may be available for manure application. If the farmer uses tanker technology to inject manure, little opportunity outside of the pre-plant season is appropriate for manure application.

An Oklahoma farmer using irrigation technology to apply lagoon effluent would have a wide range of time to apply during the growing season.

4.4.3 Pumpable Nitrogen and Phosphorus Estimation

Excreted nitrogen and phosphorus were estimated using two methods. One was the feed intake method based on the feed consumed by the pigs and an estimate of the nitrogen and phosphorus use efficiency of the animal. The second was the manure test method based on manure test results, the volume of manure generated on the farm and the percent of excreted manure land applied. The feed intake method was more highly correlated with animal units (r^2=0.87 for nitrogen; r^2=0.89 for phosphorus) but did not reflect possible differences in feed efficiency among operations. The manure test method was more poorly correlated (r^2=0.74 for nitrogen; r^2=0.64 for phosphorus). Errors in manure testing, estimating the volume of manure and the percentage of P land applied all contribute to the variability of this method. Some of the variability may also be due to differences in animal nutrient use efficiencies and diets reflected in the manure test.

4.5 Results and Discussion

Thirty-one swine operations were analyzed in five states: Iowa, Missouri, North Carolina, Oklahoma and Pennsylvania. These operations represented a wide range in number of animals (Figure 4-1), phases of production, methods of manure storage and land application strategies and quantity of manure and nutrients available for land application (Appendix A).

4.5.1 Current Manure Management Practices

The current manure management practices were analyzed for each operation to establish a baseline of information for comparison. Then, various changes in manure management requirements were analyzed and compared to the developed baseline simulation results to show the potential effect of the given management change.

4.5.1.1 Size effects on nutrient production and utilization

The USEPA proposes to continue to regulate animal feeding operations based on the number of animals in the operation. Size of operation was a good predictor of the quantity of nitrogen and phosphorus excreted by animals on the analyzed operations (Figure 4-2). Operation size represented by animal units was highly correlated with the estimated quantity of phosphorus consumed and the nitrogen and phosphorus excreted by animals (Figure 4-2) among swine operations with different phases of production.

USEPA has assumed that larger operations concentrate more manure on less land than smaller operations (Federal Register, 2001; p. 2974). The USEPA's assumption that larger swine operations have less land was weakly supported by our data. Regional differences in land management were more important than size on the analyzed swine operations. On the analyzed farms, the density of animals on controlled acres (acres owned and rented by the animal feeding operation) was positively correlated with the size of operation (Figure 4-3), but the size of operation only explained 18% of the variability in animal density. North Carolina farms had significantly higher animal density per controlled acre than farms in other surveyed states ($P<0.01$). The six farms analyzed in North Carolina had a mean of 22 animal units per acre whereas farms in the other five states had a mean of 3.5 animal units per acre. The high ratio of animal units to owned and rented (controlled) acres implied nutrient production on North Carolina operations was the most intense for their land base.

The ratio of animal units to acres provides an inaccurate picture of the balance between land and animals. The number of acres fails to capture the capacity of the land to utilize nutrients from animal feeding operations. Crops, geographic regions, soil types and site-specific factors all affect the quantity of nutrients removed annually by crops. Mean nitrogen removal varied by a factor of almost two among states, and phosphate removal capacity varied by a factor of over four (Table 4-3). North Carolina and irrigated fields in Oklahoma had higher nitrogen removal capacity than other states. Most analyzed farms in North Carolina grew bermuda grass with, in some cases, an early season rye forage crop, to utilize manure nutrients. Legumes were the most prominent part in nitrogen removal capacity in Iowa (compare nitrogen recommended and nitrogen removed).

A full understanding of the balance of land and animals requires looking at the balance of nutrients produced by the animals and the capacity of the land to use those nutrients for crop or forage production (Table 4-4). North Carolina is only marginally higher than other states when evaluating the ratio of nitrogen excreted by animals to nitrogen removal capacity (Table 4-4). North Carolina operations often have relatively few owned and rented (controlled) acres, but obtain high nitrogen utilization capacity on those acres.

Table 4-3. Mean nitrogen recommended and nitrogen and phosphorus (as P_2O_5) removal capacity on a per acre basis of operations surveyed, by state.

State	n	N recommended lb/ac	N removal lb/ac	P_2O_5 removal lb/ac
Iowa	6	84 b	164 b	55 b
Missouri	6	112 b	147 b	45 b
North Carolina	6	234 a	240 a	64 b
Oklahoma	4	142 b	142 b	23 c
Oklahoma-Irrigated	3	266 a	266 a	95 a
Pennsylvania	6	115 b	145 b	52 b
Prob. > F		<0.01	<0.01	<0.01

Notes: Means in the same column followed by a different letter are significantly different. Recommended nitrogen was 0 for legumes. Operations with irrigation in Oklahoma were listed separately from other operations in Oklahoma.

Table 4-4. Mean ratio of nutrient production and nutrient capacity of swine animal feeding operations.

State	n	Nitrogen Excreted N to N removal capacity ratio lb/ac	Phosphorus (as P_2O_5) Applied PAN[1] to N removal capacity ratio lb/ac	Excreted P to N removal capacity ratio lb/ac	Applied P to N removal capacity ratio lb/ac
Iowa	6	0.5 b	0.2 b	0.9 b	0.9 b
Missouri	6	2.7 ab	0.4 b	6.7 ab	0.7 b
North Carolina	6	3.9 a	0.2 b	17.6 a	0.7 b
Oklahoma	7	1.8 ab	0.1 b	4.9 b	0.5 b
Pennsylvania	6	2.9 ab	1.5 a	5.4 b	5.4 a
Prob. > F		0.03	0.01	0.03	0.01

Notes: Nutrient production calculated as excreted nutrients or as plant available nutrients land applied. Nutrient capacity based on crop removal capacity of acres suitable for manure application on the farm. Means in the same column followed by a different letter are significantly different.
[1] Plant available nitrogen (PAN).

The predominant practice for land application of manure on the analyzed farms was to apply manure on land controlled (owned or rented) by the animal feeding operation. All but five of the analyzed farms had sufficient land for land application of manure on controlled acres for nitrogen-based manure application with the current manure storage and handling system. The five operations without sufficient land for nitrogen application were partially dependent on land not controlled by the operation and all were located in

Pennsylvania. Pennsylvania farms required 1.4 times the land controlled by the operation for nitrogen-based land application. Operations in the other states needed a mean of 28% of their acres suitable for annual manure application based on a nitrogen application.

Costs associated with current land application practices were highest on the smallest operations (Figure 4-4). There is a diminishing benefit of scale associated with manure application costs.

4.5.1.2 Manure storage effects on nutrient utilization and land application costs

Slurry systems land apply a higher proportion of the excreted nutrients resulting in more acres of land being fertilized per animal unit ($P \leq 0.01$). Manure from pits required 0.27 acres per animal unit compared to 0.09 acres per animal unit for unagitated lagoons. The higher need for land with slurry systems reflects the lower losses of nitrogen during storage in slurry systems compared to unagitated lagoons.

Higher nitrogen losses during storage and land application in lagoon systems (predominant in North Carolina and Missouri) eliminate much of the nitrogen excreted by the animals before the manure reaches the crop. North Carolina, Pennsylvania and Missouri had the highest ratio of excreted nutrients to owned or rented (controlled) land capacity (Table 4-4). After manure storage and land application, there is no difference among states, except Pennsylvania, in the ratio of manure nutrients available for the crop to nutrient capacity of the land base (Table 4-4). A similar pattern is found for phosphorus because most of the phosphorus is deposited in sludge retained at the bottom of most lagoon systems.

Costs for land application were similar for lagoon and pit systems ($P=0.25$) despite the greater land requirements for pit systems. Mean cost per animal unit was $10.17 for lagoons and $13.31 for pit systems. Cost per gallon for land application of lagoon effluent was less than half of that of pit slurry systems ($0.011 vs. $0.004). Lower volume of manure associated with slurry operations offset the higher cost per gallon of applying slurry manure.

Pit systems were consistently able to obtain more fertilizer value from their manure on an animal unit basis ($P \leq 0.01$). The greater fertilizer value of slurry manure was able to offset the added cost of accessing more land. Net costs of manure application (cost of application less fertilizer value of manure) were lower on farms with pit manure. Net manure application costs on farms applying manure from slurry systems was $1.25 per animal unit compared to $6.76 per animal unit for operations applying unagitated lagoon effluent. Compared simulation results show that 6 of 13 operations spreading slurry were able to apply manure profitably on their farm compared to only 3 of 16 applying lagoon effluent (two operations had multiple manure forms (e.g. a pit and a lagoon) on their farm and were not included in this comparison).

This conclusion assumes farmers are capturing the fertilizer value of the manure being applied. To capture manure fertilizer value, farmers need to reduce rates of nitrogen, phosphorus and potassium from other purchased sources on land receiving manure and then harvest a crop with value from the land. Value can be realized as grain or hay from crop ground and meat and milk from pastures. On 88% of the farms, all the manure was being applied to owned or rented ground. The high proportion of the manure being applied to land controlled by the farmer makes it more likely that farmers are capturing at least some of the manure value under the current system.

4.5.1.3 Feasibility of land application equipment

4.5.1.3.1 Pit systems

Characteristics of the 15 operations that handled pit manure are summarized in Table 4-5. Mean minimum application rate for these slurry systems was 4,497 gal/acre with nitrogen-based management. The lowest calculated application rate for slurry operations was 2,390 gal/acre for an Iowa operation (IA-4) with 525-animal units that had a small tractor-pulled spreader with a discharge rate of 350 gal/min. Mean discharge rate among the 14 operations was 728 gallons per minute; mean swath width was 14 feet for injection and 25 feet for surface applications.

Table 4-5. Application parameters for farmers using pit slurry storages and applying on a plant available nitrogen limit.

Presentation Code	Application Technology	Placement	Minimum Application rate (gal/acre)	Discharge Rate (gal/min)	Swath Width (ft)	Travel Speed (mph)
IA-1	Tanker, tractor	injection	4,080	600	15	4.9
IA-3	Tanker, tractor	injection	5,580	800	15	4.7
IA-4	Tanker, tractor	injection	2,390	350	15	4.8
MO-2	Tanker, tractor	injection	3,680	425	12	4.8
IA-2	Tanker, tractor	surface	12,000	1,000	15	2.8
IA-5	Tanker, tractor	surface	4,380	650	15	4.9
IA-6	Tanker, tractor	surface	4,950	800	30	2.7
OK-5	Tanker, tractor	surface	3,000	600	20	5.0
PA-4	Tanker, tractor	surface	4,560	1,000	40	2.7
PA-5	Tanker, tractor	surface	3,550	800	25	4.5
Means			4,817	703	20	4.2
PA-1	Tanker, truck	surface	3,770	725	16	6.0
PA-2	Tanker, truck	surface	5,030	1,000	30	3.3
PA-3	Tanker, truck	surface	3,880	850	20	5.4
PA-6	Tanker, truck	surface	3,160	800	40	3.1
Means			3,960	844	27	4.5
MO-3	Dragline	injection	3,450	520	15	5.0

Most applicators were operating near their maximum application speed (see Chapter 3). Mean travel speed for tractor-pulled spreaders was 4.2 miles/hour; mean travel speed for truck-mounted tankers was 4.5 miles/hr.

Operations using tractor-pulled or truck-mounted tanker spreaders operated their equipment for an average of 118 hours/year doing land application activities (loading the tanker, road travel, in-field travel and application time). The average operation spent 20% of this as road travel time (range 4 to 46%) and 37% of this time discharging manure (range 21 to 53%). The size of the swine operation was a good predictor of the amount of time required for land application of manure utilizing tanker spreaders (Figure 4-5).

4.5.1.3.2 Lagoon systems

Characteristics of the 17 operations that handled lagoon effluent through irrigation systems are summarized in Table 4-6. Mean minimum application rate for these lagoon systems was 27,649 gal/acre using nitrogen-based management. Mean discharge rate among the 17 operations was 383 gallons per minute.

Table 4-6. Application parameters for farmers applying lagoon effluent using irrigation systems and applying based on a plant available nitrogen limit.

Presentation Code	Application Technology	Placement	Minimum Application Rate (gal/acre)	Discharge Rate (gal/min)	Swath Width (ft)	Travel Speed (ft/min)
MO-1	Traveling gun	surface	18,465	200	300	1.6
MO-5	Traveling gun	surface	27,154	400	250	2.6
NC-2	Traveling gun	surface	27,154	300	200	2.4
NC-3	Traveling gun	surface	27,154	300	225	2.1
NC-4	Traveling gun	surface	27,154	250	250	1.6
NC-5	Traveling gun	surface	27,154	295	275	1.7
NC-6	Traveling gun	surface	27,154	350	260	2.2
OK-4	Traveling gun	surface	27,154	325	300	1.7
OK-5	Traveling gun	surface	27,154	320	300	1.7
Mean			26,189	304	262	2.0
NC-1	Stationary sprinkler	surface	27,154	200	90	-
OK-1	Stationary sprinkler	surface	27,154	450	160	-
OK-3	Stationary sprinkler	surface	27,154	225	180	-
Mean			27,154	292	143	-
MO-4	Dragline	injection	27,154	750	12	1.1[1]
MO-6	Dragline	injection	16,564	650	12	1.6[1]
Mean			21,859	700	12	1.4[1]
OK-2	Center Pivot	surface	16,835	500	-	-
OK-6	Center Pivot	surface	14,935	500	-	-
OK-7	Center pivot	surface	77,389	500	-	-
Mean			36,386	500		

[1] Units are mph for these values only.

Most applicators were operating well below their maximum application speed (see Chapter 3). Mean travel speed for traveling guns was 2.0 ft/min; mean travel speed for dragline injection was 1.4 miles/hr.

Operations applying lagoon effluent operate their equipment an average of 142 hours/year doing land application activities (setting up irrigation pipe, setting up pull of traveling gun (when applicable) and application time). The average operation spent 6% of this time setting up the pipe network (range 0 to 23%) and 84% as application time (range 53 to 100%). No correlation existed between operation size and application time for lagoons (Figure 4-5).

4.5.1.4 Travel distance and time of application effects

Time required to land apply manure is a major component of the feasibility of any manure management strategy. Pit slurry is difficult to apply during the growing season so farmers tend to apply it before planting and after harvesting row crops and as a surface application on hay during the summer.

At least two seasonal constraints are possible under the proposed EPA rule. First, the EPA believes that “many permit writers will find a prohibition on applying CAFO-generated manure to frozen, snow covered or saturated ground to be reasonably necessary to achieve the effluent limitations and to carry out the purposes and intent of the CWA… (Federal Register p. 3039).” Second, post-harvest (e.g. fall) application may be restricted or prohibited because “Permit authorities would be expected to develop restrictions on timing and method of application that reflect regional considerations, which restrict applications that are not an appropriate agricultural practice and have the potential to result in pollutant discharges to waters of the United States (Federal Register p. 3039).”

4.5.1.4.1 Pit systems

Mean travel distance between manure storage and the field for manure application was increased with operation size (Figure 4-6). Pennsylvania farms had greater travel distance than Iowa farms (*P=0.1)*, in part because analyzed Pennsylvania farms were larger than analyzed Iowa farms. Operations currently spend an average of 20% (range of 4 to 46%), or 26 hours (range 3 to 116 hours), of their manure application time in road travel from manure storage to field.

Iowa has a restrictive manure application window. The predominate crop system of corn/soybean rotation requires applying slurry before planting in the spring and after harvesting in the fall. Fieldwork hours prior to corn planting are estimated at 173 hours (Table 4-2). The maximum application time for the Iowa farms modeled was 132 hours, sufficient for pre-plant application. Two of the six Iowa farms used multiple tankers to reduce the amount of time that would actually be spent land applying manure.

Only two of the six Iowa farms had 12-month storage capacity; the remaining four had 4- to 6-month storage capacities. Short storage capacity requires application of manure during the growing season or after harvest in the fall. If the USEPA permit writers do not permit fall application, these farms would need to make significant investments to increase their manure storage capacity.

Pennsylvania farms had the largest annual application time of 121 hours. This allowed application prior to planting corn. The average size manure storage in PA was a 7-month capacity; with none of our modeled farms having 12-month capacity. PA farmers applied manure to hay during the summer and several applied manure after wheat harvest in the summer to keep the pit storage from over-flowing. The proposed regulations may prohibit application of manure after wheat harvest in mid- to late-summer because the land is not planted to a crop for several months and manure nitrogen may volatilize before it can be used for crop production.

4.5.1.4.2 Lagoon systems

None of the lagoon systems experienced time constraints applying lagoon effluent within the appropriate application time windows. All producers in North Carolina and Oklahoma and two producers in Missouri with lagoons used irrigation technologies (spray fields, center pivots and traveling guns) to apply effluent to growing crops. The long growing season in these states permits long application windows.

Two of the four Missouri producers with lagoons used dragline and tanker technology to apply lagoon effluent. This requires application prior to planting corn. MO-6 is estimated to take 119 hours to apply effluent. Only 74 hours are estimated to be fieldwork hours according to the USDA statistics (Table 4-1). This person already applies effluent to land in the spring and fall. Limits on fall application would impact this producer’s management.

4.5.1.5 Land Application Technology Effects On Manure Application Cost

Table 4-7 presents the types of application technologies used and their prevalence by state on the analyzed farms. The irrigation technologies (traveling gun, center pivot and stationary sprinklers) were used exclusively to distribute lagoon effluent. Dragline technology is used to distribute both lagoon effluent and pit slurry. Tanker technology is used predominately to distribute pit slurry but also was used to apply lagoon effluent, particularly when the producer had both lagoon and pit storages.

Traveling gun systems are the most common system for land applying anaerobic lagoon effluent. The average cost was $.006/gallon of effluent applied. Traveling guns are the most expensive irrigation technology used but are less labor intensive than stationary sprinklers and provide more flexibility to irrigate additional land areas than center pivots.

Center pivots are the least expensive manure distribution system ($.001/gallon) where producers use irrigation equipment designed for water application on crops to also distribute manure effluent. Application of lagoon effluent will not, especially in arid regions, provide adequate moisture for maximum crop production without the application of additional water through the irrigation system.

Stationary sprinklers are inexpensive manure distribution systems ($.003/gallon) that are very labor intensive. Stationary sprinklers are appropriate to distribute effluent on small acreages but become labor prohibitive when many acres are needed to appropriately distribute effluent.

Table 4-7. Frequency for different types of manure application technology used on the analyzed operations.

Type of application	IA	MO	NC	OK	PA	Grand Total
Traveling gun		2	5	2		9
Center Pivot				3		3
Stationary sprinkler			1	2		3
Dragline		3				3
Tanker, tractor	5	1			2	8
Tanker, truck	1				4	5
Grand Total	6	6	6	7	6	31

Dragline systems use 4-inch to 6-inch hoses that transport manure from the manure storage to the fields. The hoses are dragged behind a tractor equipped with a tool bar injector that distributes the manure over a 12- to 18-foot swath. Dragline systems had an average application cost of $.006/gallon. Dragline systems typically injected or incorporated manure during land application.

Tractor-pulled tankers were most commonly used to apply pit slurry in the Midwest (IA and MO). The average cost of $.012/gallon was the most expensive application system but permitted hauling of manure greater distances and allowed access to land areas not available with other technologies. Tractor-pulled tankers are frequently used to inject manure.

Truck-mounted tankers were more common in PA and were used when surface application was practiced. Wider swath widths of 25 to 40 feet allow low application rates. Using a truck as power unit for the tanker allows increased transportation speed but limits the power available to incorporate the manure. Truck-mounted tankers had an average cost of $.007/gallon of slurry applied.

The reported costs of manure application are based on the current management technologies used by the producer. Some producers own their equipment and apply their manure; while others producers custom hired their manure application. Five of the seven producers who used custom applicators hired ones who used more than one tank to apply the effluent. This reduced the amount of time spent applying manure on that particular farm. Two producers owned more than one traveling gun to manage their effluent application.

Tractors used to pull manure application tankers were used for other activities on the farm. Their equipment complements were sized to fit the needs of the whole farm. Farms with significant cropping activities had larger tractors and tankers. Small farms tended to have small tractors pulling small tankers (OK-5 and IA-3).

Producers who use traveling guns and solid set sprinkler systems tended to have smaller tractors that are used to assist in operating the manure distribution equipment.

4.5.1.6 Indicators of economic viability of current management practices

The USEPA uses as its primary criteria for determining financial impact of the proposed regulations the Sales Test. The sales test is defined as the cost of compliance (incremental) as a percent of gross revenue. Presumably the cost:sales ratio gives an idea of profitability and the ability of producers to pay for certain activities. Cost:sales ratios for current nitrogen-based management on the 31 farms analyzed are reported in Table 4-8.

Table 4-8: Cost:sales ratios for farms applying manure on a plant available nitrogen basis.

Cost:sales	All farms		Contract growers		Independent producers	
Ratio	Frequency	Percentage	Frequency	Percentage	Frequency	Percentage
Less than 1%	9	29%	0	0%	9	50%
Less than 2%	6	19%	0	0%	6	33%
Less than 3%	5	16%	2	15%	3	17%
Less than 5%	5	16%	5	38%	0	0%
Less than 10%	5	16%	5	38%	0	0%
More than 10%	1	3%	1	8%	0	0%
Total	31	100%	13	100%	18	100%

Those farms with cost:sales ratio higher than 5% are all contract producers. The average cost:sales ratio was 6.1% for contract producers (minimum of 2% and maximum of 10%) and 1.3% for independent producers. This significant difference demonstrates that manure management is a larger part of the contract producer’s total responsibility than it is for independent growers. Whereas independent growers are responsible for all activities associated with pork production, and must be compensated for performing those activities, contract growers have a more limited set of responsibilities for which they are compensated. Contract producers have been contracted to provide facilities, utilities, labor and manure disposal.

The high cost:sales ratio for manure management of contract producers reveals an oversight in the EPA economic analysis. The EPA assumed gross sales for all modeled operations to be the combined grain and livestock sales of the farm and assumed that all livestock were sold at market price. Contract producers do not get market price for the animals they raise and thus have less cash flow flexibility than an independent producer to implement management changes.

The other criteria the EPA uses for financial impact is the cash flow test and the debt to asset ratio. Presumably, the cash flow test would be a measure of liquidity and the debt to asset ratio a measure of solvency. However, the cash flow test as used by the USEPA is a second test of profitability and gives little information regarding the ability of a farm to pay expenses (liquidity).

Our model could estimate a discounted cash flow for each operation; however, we chose not to do this because discounted cash flow is a measure of profitability rather than liquidity – the ability to pay for expenses. Balance sheet information was not collected on the farms modeled and no estimate of the solvency of the farms is made in this economic analysis.

According to traditional economic analysis, we chose to use return on assets (ROA) as a measure of profitability and cash flow analysis to evaluate liquidity.

The appropriate measure of profitability is the ROA because it standardizes income for the amount of assets invested to obtain the return. Over a 10-year planning horizon, we estimate that the 31 modeled farms had an average return on assets of 21%, a minimum of 6% and a maximum of 46%. Independent producers had an average ROA of 26%; contractors, 12%. This indicates that the farms are generally profitable but it does not tell whether they have liquidity.

Liquidity is measured by cash flow of the 31 modeled farms and is difficult to summarize statistically. All farms had a small positive annual cash flow while paying loans on their buildings and equipment. After paying off investments, cash flows tended to rise. Our model used 10-year average prices for feedstuffs purchased and animals sold so it does not account for the wide fluctuations that occur in the market prices of agricultural commodities.

One of the major impacts of the proposed rule is the requirement for nutrient management planning consisting of manure and soil sampling and the record keeping requirements to be in compliance with a permit. Using state-specific university recommendations we estimated the expense of nutrient management planning. Our analysis of costs indicated an average of 10% of manure management costs currently are attributable to nutrient management planning activities.

4.5.2 Phosphorus-based manure applications

The ultimate impact of phosphorus-based application rates is entirely dependent on how they are imposed on the operation. Within the proposed USEPA rules are a large number of options and proposals that would have implications on the costs and feasibility of phosphorus-based manure management. Will USEPA insist on annual phosphorus limits or allow rotational phosphorus limits? Will lagoon operations be required to agitate their lagoons to insure land application of all excreted phosphorus? The many potential outcomes of the phosphorus rule make a straightforward, concise analysis difficult.

In this section we address the effect of potential phosphorus-based rules on the feasibility of manure application rates, land requirements, time requirements and costs.

USEPA in their analysis of the proposed rule focused primarily on the costs associated with the proposed rule. In our analysis of the rule we determined that feasibility issues, not costs, were the most obvious barriers to a farmer implementing the rule.

The three types of manure handling systems discussed in this report are: pit systems, unagitated lagoons and agitated lagoons.

The feasibility of phosphorus application rates for lagoon systems is dependent on how the proposed rule is implemented. All lagoon operations analyzed applied unagitated lagoon effluent. One possible scenario is lagoons will continue to be regulated based on the nutrients that are land applied from an unagitated lagoon. Under this scenario much of the phosphorus (possibly as high as 95%) remains in the lagoon sludge layer. A second scenario is that anaerobic lagoons will be agitated on a scheduled basis to mix the nutrients in the sludge with the effluent that is land applied.

4.5.2.1 Feasibility of manure application rate

4.5.2.1.1 Pit systems

The impact of phosphorous-based application rates on swine operations that store manure in pits and apply slurry depends on how the phosphorous rate limits are imposed. Phosphorus rates restricted by the annual phosphorus requirement of the crop create significant feasibility issues on the majority of farms analyzed. A four-year phosphorus rotation application rate was not feasible when applied to low productivity, low phosphorus removal crops (dryland range).

4.5.2.1.1.1 Annual phosphorus limits

Annual phosphorus rates required reducing manure application rate an average of 73% on slurry-based operations. Mean minimum application rate was 1,416 gal/acre for the 15 operations that predominantly stored manure as slurry (Table 4-9). The mean minimum application rate was reduced to 946 gal/acre if data from one Iowa operation with low uncharacteristically manure phosphorus concentrations were not included.

Application rates as technologically feasible with current equipment if they could be attained by decreasing discharge rate to 400 gal/min and increasing travel speed to five mph for tractor-pulled spreaders and six mph for truck-mounted spreaders. These modifications to existing equipment and equipment operation reduced application rate an average of 50% compared to a needed mean reduction of 71%.

Annual phosphorus-based application rates were feasible for four of the 15 operations. Reducing discharge rate was necessary for three of these four operations to meet this requirement. Reducing discharge rate required a financial investment to modify the manure application equipment(see Chapter 3). Most tanker-type applicators do not have a recommended method for reducing discharge rate for slurries. The remaining 11 slurry-based operations cannot apply manure at annual phosphorus rates with their current equipment.

There is no equipment currently on the market capable of injecting manure to meet annual phosphorus limits on these operations. The lower extreme limit for injection of manure is currently near 2000 gal/acre (400 gal/min discharge rate, 20-foot swath width and five mph travel speed). This is above the required annual phosphorus application rate of these 11 operations (Table 4-9). Injection of swine manure slurry is not a feasible technology with currently available manure application equipment if application rates are dictated by annual phosphorous limits.

Table 4-9. Mean minimum application rate of manure slurry from 15 swine operations for three strategies for determining application rate.

Operation	Nitrogen	Annual Phosphorus	Rotational Phosphorus
IA-4	2,390	630 I,T	2,390
OK-5	3,000	220 I,T	890 I, T
PA-6	3,160	1,420	3,160
MO-3	3,450	830 I	3,450
PA-5	3,550	640 I,T	3,550
MO-2	3,680	1,040 I	3,680
PA-1	3,770	1,050 I	3,770
PA-3	3,880	1,020 I	3,880
IA-1	4,080	1,500 I	4,070
IA-5	4,380	750 I,T	4,260
PA-4	4,560	1,030	4,560
IA-6	4,950	700 I,T	3,570
PA-2	5,030	1,180	5,030
IA-3	5,580	1,240 I	5,600
IA-2	12,000	8,000	12,000
Mean	4,497	1,417	4,257

Notes: Current requirements are for nitrogen-based rates; USEPA is proposing annual phosphorus limits; rotational phosphorus limits allow application of up to 4 years of phosphorus in one year and then no further applications until crop removal has utilized the excess manure phosphorus. Values followed by an “I” were determined to be not feasible for equipment currently owned by the farmer but feasible if the operation switched to surface application and bought equipment capable of discharging a 40-foot swath at 400 gallons/minute;. Values followed by a “T” were determined to be not feasible for most equipment currently on the market.

Application rates are defined as technologically possible if they were greater than 990 gal/acre for tractor-pulled spreaders and 825 gal/acre for truck pulled spreaders. To attain this low rate of application, manure would need to be surface applied at a discharge rate of 400 gal/min, swath width of 40 feet and travel speed at the maximum attainable (5 mph for tractors, 6 mph for trucks). These modifications reduced application rate an average of 77% compared to a needed mean reduction of 71%. One fifth of the operations (3 of 15); however, would not be capable of achieving annual phosphorus application rates after implementing discharge rate reductions and travel speed increases (Table 4-9).

In summary, adopting a higher travel speed, wider swath width, and/or lower discharge rate strategies would require changes in current land application practices for most of the 10 operations to meet annual phosphorus limits. Injection operations would need to convert or purchase new equipment capable of surface application. Surface application of manure increases the potential for odor generation. Eight of the 10 operations would need to modify equipment to increase the width of application, by a factor of almost three. Reducing discharge rate also increases time required for land application of manure. Most operations would be required to increase travel speed during manure application to comply with annual phosphorous application limits.

All these changes are within the technical performance standards of existing equipment, implementation may not be feasible in all operations. Increased travel speed may not be safe or feasible on some sloped or rough fields. A 40-foot swath width may not be compatible on some fields or make areas of some fields inaccessible.

Forcing operations to surface apply manure contradicts other best management practices for manure. Many operations are currently adopting injection of manure to reduce odor and minimize ammonia losses from manure. The USEPA is advocating the concentration of nutrients in manure by reducing water inputs. This further concentrating of manure nutrients and will make it more difficult for operations to attain annual phosphorus rates. Feeding strategies to reduce phosphorus excretion will improve the feasibility of annual phosphorus limits.

Reduced discharge rates will increase the time required to land apply manure. Thirteen of the 15 operations would need to reduce manure discharge rate to meet annual phosphorus limits. Mean reduction was 46% with eight operations requiring a reduction in discharge rate of 50% or more. Reducing discharge rate to 400 gal/min would increase time required for manure application by an average of 42 hours/year (range 3 to 82 hours/year). Reducing discharge rate to 400 gal/min would increase land application time by 33% (range 3 to 65%) compared to current management practices. These estimates of reduced application rate and time effects may underestimate true values because reducing manure discharge rate to 400 gal/min was insufficient to meet annual phosphorus limits in five of the 13 farms.

Increased time for land application, as required for implementing an annual phosphorus rule, may hinder the farmer’s ability to apply manure in a timely manner for crop utilization. The increased time associated with decreasing discharge rate to 400 gal/min was equal to 12% of the pre-plant work hours in Iowa and Pennsylvania (range 0 to 23%).

Increased time for land application was not affected by operation size (*P*=0.36). Mean increase in application time due to reducing discharge rate to 400 gal/min was 0.06 hours/animal unit.

Implementing an annual phosphorus rule, where feasible, increases costs of application by requiring equipment modifications and increasing hours that tractors or truck are used. The initial cost of modifying tanker pumps to discharge at a 400 gal/min rate is estimated to be $10,000 to $12,000 per tank. This modification increases the cost of a new tank 25% to 30%. Tractors rental is approximately $50/hour and labor is $10/hour so it could be expected that applying manure an annual phosphorus rate would increase application costs by at least $60 for every hour increase over the nitrogen based application rate.

Annual phosphorus application rates were not feasible for slurry-based swine operations. One-fifth of the analyzed operations could not meet the standard because current equipment cannot apply the low rates required by the annual phosphorous application limit. Injection of slurry manure would be infeasible for any of the operations studied because of the low manure application rate. The remaining 80% of the swine operations capable of attaining an annual phosphorus limit application rate with slurry would need to surface apply manure at the maximum application speed, increase to 40-foot swath width and reduce discharge rate by nearly 50%. Reduced discharge rate alone will increase land application time at least 33% and use 12% of the pre-plant field time available to farmers in Iowa and Pennsylvania. Forcing farmers to adopt high travel speeds, low discharge rates, and surface application strategies may result in safety concerns, and increase odor and ammonia emissions because injection of manure is not feasible with existing application equipment.

4.5.2.1.1.2 Rotation phosphorus limits

Adopting rotation-based phosphorus limits had little effect on the feasibility of manure application rates relative to nitrogen application rates for slurry operations. We evaluated a four-year rotation phosphorus limit that allowed farmers to apply up to four years of phosphorus when manure was applied. No additional manure applications are made until the phosphorus has been utilized by crops grown on the land. Manure application could not exceed the annual nitrogen requirement of the crop grown during the application year.

Rotation phosphorus application rates allowed all but four operations to continue to land apply manure at the same rate as the nitrogen-based rate in the years that fields receive manure (Table 4-9). Mean minimum application rate was 4,257 gal/acre for the 15 operations that applied manure predominantly as a slurry. This mean minimum application rate is 2% less than the application rate required by nitrogen-based management (Table 4-9). All but one operation could adjust application rate from nitrogen-based rates to phosphorus-based rates by adjusting travel speed.

Consequently, rotational phosphorus rates have no effect on discharge time and costs of manure applicator operation when compared to current nitrogen-based application rates.

The exception was an operation applying manure to dryland range in Oklahoma (OK-5). Forage productivity was low (2 tons/acre). The combination of low forage yield and crops with a high nitrogen to phosphorus ratio resulted in limited phosphorus removal on this pasture-based operation. This case study emphasizes that continued slurry application on low productivity pasture land may not be feasible under any form of phosphorus application rule.

This analysis assumes that rotation phosphorus limits allow up to four years of phosphorus to be applied to fields in the years that manure is applied. Longer phosphorous application rotations (more than four years) may make low productivity soil locations feasible. Mandating shorter phosphorous rotations (less four years) increase the potential that other operations will encounter manure application rates that are not feasible. Slurry manure application rates required by a strict interpretation of the annual phosphorus limits resulted in manure injection applications not being feasible for all operations and surface applications not being feasible on at least 20% of the slurry operations studied.

4.5.2.1.2 Unagitated Lagoon systems

All phosphorus limited application rates were feasible for all operations applying unagitated anaerobic lagoon effluent.

All analyzed lagoon operations currently apply unagitated lagoon effluent. These operations were able to meet annual and rotation phosphorus limits by implementing changes in application speed and/or adjusting the number of effluent applications to the field. No operations had to change discharge rate or swath width. Consequently, there was no effect of phosphorus rules on the length of time needed to pump unagitated anaerobic lagoon effluent from the storage.

Average discharge rate of the 16 operations was 367 gal/min and average swath width was 193 feet.

Nitrogen, rather than phosphorus, limited manure application rates in five of the 16 analyzed unagitated lagoon operations. These operations would make no changes in manure application rates based on phosphorus limit rules. Three of the 13 operations capable of adjusting travel speed had to make adjustments in travel speed. The solid set and hand-carry irrigation systems were able to meet the application requirements of phosphorus limits by reducing the duration of the irrigation period.

4.5.2.1.3 Agitated Lagoon systems

Lagoon agitation would pose major feasibility issues for operators using irrigation systems for land application of manure. Annual phosphorus application rates of agitated lagoon effluent would not be feasible for all sprinkler-based or traveling gun type systems. These operations would be required to modify or convert to a different system of manure application.

Agitation of anaerobic lagoon effluent based on annual phosphorous limits resulted in low manure application rates not feasible for at least five of the 16 irrigation-based systems. These operations would be required to convert to a new manure handling system such as tanker spreader or dragline injection. Pivot irrigators may have problems handling agitated lagoon effluent because of increased solids content.

4.5.2.2 Land requirements

In this section we address the effect of phosphorus limits on the amount of land required for manure application and the distance needed to travel to reach that land.

4.5.2.2.1 Pit systems

Pit systems converting from a nitrogen-based to a phosphorus-based land application system require significantly more land ($P \leq 0.01$). The 14 operations that handled all their manure in slurry form required more than three times more land for phosphorus-based manure management: 0.3 acres/animal unit for nitrogen-based application, 1.0 acres/animal unit for phosphorus-based application.

Operations owned or rented (controlled) sufficient land to address 40% of the additional land needed for implementing a phosphorus rule. Only three of these 14 operations had sufficient owned or rented land (controlled acres) for phosphorus-based management (0% additional land needed). Under nitrogen-based management 9 of the operations had sufficient land available for manure application. Five operations need to find 100% of the additional land needed because they were presently applying manure on non-owned or non-rented land. Smaller operations were more likely to have sufficient land to meet the additional requirements of a phosphorus rule (Figure 4-7) but operation size only explained 35% of the relationship between animal units and additional land need. All the farms that needed to locate100% of the additional land needed for manure application from currently uncontrolled acres were in Pennsylvania.

The 11 land-deficient operations needed to locate an average of 512 additional acres for phosphorus-based application in addition to the land they currently own or rent (range 75 to 1369 acres) or 0.6 more acres/animal unit.

An annual phosphorus rule would require the farmer to access all of these extra acres every year. Using a nitrogen-based phosphorus rotation limited by four-year phosphorus need would allow applying manure on a fraction of the total acres each year and then rotating to different acres in the following years. The average number of acres receiving manure in any given year was only 18 acres more for a phosphorus rotation than for the current nitrogen-based approach among the 14 operations applying slurry.

Tanker- and truck-mounted slurry spreaders increased road travel distance and time to reach the additional fields needed for phosphorus based manure applications by an average of 0.5 miles ($P \leq 0.01$). Operation size is positively correlated with mean travel distance to the field for manure application ($y = 0.41 + 0.0012\ x$, $r^2 = 0.35$).

Traveling the extra distance increased the proportion of land application time spent in road travel from 20 to 34% of the time spent applying manure. Operations spent between 0 to 139 additional hours transporting manure to more distant fields (mean=38 hours). Operations with multiple pieces of manure application equipment can reduce the impact of the added time by using two or more pieces of equipment simultaneously. Five of the slurry-based operations used more than one tanker to apply manure. Use of multiple applicators reduced mean travel time from 38 to 27 hours (range 0 to 66 hours).

The additional road travel time associated with phosphorus limits on slurry operations will create a significant challenge to farmers using manure to fertilize corn on some operations. The proposed rules emphasize timely application of manure as a fertilizer. For operations applying slurry manure for corn this implies application during the spring pre-plant period. Additional road travel time averages 15% of the pre-plant hours available for corn planting. For four of the operations, the additional road travel time represents 50 to 65 additional hours of work or an average of 26% of the available fieldwork time during the spring pre-plant period for corn (see Table 4-2).

Manure application will be made on all acres every year with annual phosphorus limits so average road time should remain relatively constant from year to year. With rotation phosphorus limits, the mean travel time over the rotation will be the same as for annual phosphorus limits because the same volume of manure will be applied. In specific years, the average travel time may be above or below the average, depending on which fields receive manure application that year. The farmer will need a system with the capacity to transport the volume of manure in a timely manner for those years with the most road travel time.

Our analysis is a conservative estimate of the additional road travel time a producer may require to meet phosphorus application limits. We assumed all owned and rented land was available for manure application. It was also assumed that neighboring farms would be willing and able to accept manure from the CAFO. We estimated the mean travel distance from the swine production operation to eight contiguous neighboring farms based on the presence of roads and agricultural land shown in aerial photos. Mean travel distance to neighboring farms was two miles (range 0.8 to 5.2 miles) for tanker operations. PA producers in our study currently transport manure an estimated average of 1.9 miles each year. IA producers are estimated to transport manure an average of 1.5 miles each year. Farmers that need to travel farther than neighboring farms will spend additional time transporting manure.

Greater travel distances will increase the transport time and cost. Using custom rates from our survey of PA farms and equation 4-1 below we estimate the cost to transport 1000 gallons 1 mile to be $.51. The 5 PA farms produce an average of 1,248,446 gallons of manure annually. On average costs increase about $640/year or

$0.58/animal unit for each additional mile the manure must be transported. Each additional mile adds about 7% to the cost of manure application.

$$Cost\ per\ 1000\ gallons\ per\ mile = \frac{Custom\ charge\ (\$/hr)}{\frac{1000\ gallons}{load} \times \frac{miles}{hour}} \qquad \text{Eq. 4-1}$$

In summary, phosphorus limits tripled land requirements for slurry-based operations. This reduced the number of operations able to apply only to owned and/or rented land (controlled acres) from 65 to 35%. On average, operations applying manure based on a phosphorus rule applied 40% of the manure to controlled acres. The increased land requirements forced farmers to increase manure transport distances for access to land that can receive manure. The slurry-based operations in this analysis would increase average distance traveled to fields by at least 0.5 miles. The mean increased travel time was equivalent to 15% of corn pre-plant work time and averaged 25% on the 30% of operations most affected by the increased land requirements.

4.5.2.2.2 Unagitated lagoon systems

All lagoon based operations currently spread unagitated effluent on land owned or rented by the farm. Operations used 18% of their owned and rented (controlled) acres for effluent application (range 2 to 66%). The mean acreage needed per animal unit on these operations was 0.09.

Phosphorus limits increased land requirements on 11 of the 16 farms that stored manure in unagitated anaerobic lagoons. Annual phosphorous limits increase the mean current land requirements of 60 acres up to 80 acres. Annual phosphorus limits increased land required per animal unit to 0.13. One operation had insufficient land to meet the requirements of a phosphorus rule and a second operation had only the needed acres with no land available for contingencies such as high manure volumes or low crop yields. Swine operations applying unagitated lagoon effluent use an average of 55% of their owned and controlled acres.

Rotation phosphorus limits resulted in similar land requirements as annual phosphorus limits with unagitated lagoon effluent.

4.5.2.2.3 Agitated lagoon systems

Any requirement to agitate anaerobic lagoons combined with a requirement to apply effluent based on phosphorus content of the manure will result in higher land application area requirements. These operations would experience average land area requirement increases per animal unit from 0.09 to 1.3. These operations would require about ten times the land area they currently own or rent.

North Carolina operations would experience the greatest impact and would require more than 16 times their current land base. Oklahoma farms would be significantly less impacted (P=0.08) needing to locate four times their current land base. Only two operations, both in Oklahoma, had sufficient land to switch to an agitated lagoon system on a phosphorus limit basis and be able to continue applying manure to land they currently own or rent.

4.5.2.3 Time effects

4.5.2.3.1 Pit systems

The annual phosphorus rule increased both road travel time and land application time. Average total increase in manure handling time was at least 77 hours/year (range 7 to 228 hours). Operations with multiple pieces of manure application equipment can reduce the impact of the added time by using multiple pieces of equipment simultaneously. Five of the slurry-based operations used more than one tanker to apply manure. Use of multiple applicators reduced mean handling time from 77 to 54 hours (range 7 to 147 hours). It should be noted that even with these changes in manure management, 33% of the operations still were unable to attain annual phosphorus limits.

The additional time associated with annual phosphorus limits on slurry operations will create a significant challenge to many farmers using manure to fertilizer corn. The proposed rules emphasize timely application of manure as a fertilizer. For operations applying slurry manure for corn this implies application during the spring pre-plant period. The additional time represents an average of 28% of the pre-plant hours of work for corn, but is over 50% of the pre-plant hours on three case study farms.

Farmers faced with such a significant increase in workload during the busy spring season will need to adopt strategies to limit manure application time. Possible options include purchasing additional land application equipment so more manure can be applied in a shorter period of time. This option would reduce the duration of manure application but not the total labor needs during the land application period. Satellite storage cell, nurse tanks and larger and faster tankers will shift road transport time from the busy period or reduce manure transport time. The costs of these strategies were not evaluated but it is anticipated that many slurry based operations will need to change current practices because of these time constraints.

An alternative to annual phosphorus limits is the four-year phosphorus rotation approach. This approach allows manure application to meet the four-year phosphorus need with out exceeding the annual nitrogen requirement of the crop in the year of manure application. No additional manure is applied until crops remove the applied phosphorus. Using this strategy, all but one operation was able to meet rotation phosphorus limits without increasing application time (see section 4.5.2.2.1). On this operation, phosphorus limits of either type are infeasible with currently available equipment and so time effects could not be calculated (see section 4.5.2.1.1.1)

Using the rotation phosphorus limits, the primary increase in manure handling time from the phosphorus limit is from increased road travel time from the manure storage to the field for application. The added acre requirements resulted in farmers traveling greater distances to apply manure (see section 4.5.2.2.1).

Average total increase in manure handling time was at least 38 hours/year (range 0 to 147 hours) with a four-year rotation phosphorus limit. Operations with multiple pieces of manure application equipment can reduce the impact of the added time by using these multiple pieces of equipment simultaneously. Five of the slurry-based operations used more than one tanker to apply manure. Use of multiple applicators reduced mean handling time from 38 to 27 hours (range 0 to 66 hours). Further discussion of increased road time associated with rotation phosphorus limits is presented in section 4.5.2.2.1.

Rotation phosphorus limits increase application time requirements 24% compared to 58% for annual phosphorus limits. Rotation phosphorus limits have no impact on discharge rate and land application time whereas annual limits have the potential to increase manure discharge time an average of 42 hours/year. Mean manure handling time was 93 hours per year for nitrogen-based management, 117 hours per year for rotation phosphorus limits and 147 hours per year for annual phosphorus rates. Adopting rotation phosphorus rates will present time management challenges for some farmers; adopting annual phosphorus limits will present time management problems for most farmers.

Table 4-10. Mean effect of three methods of limiting manure application on selected measurements of related to manure application time (31 swine operations).

Parameter	Units	Nitrogen Limit	Annual Phosphorus	4-year Phosphorus Rotation Limit
Equipment operation duration[1]	hours	127	201	162
Manure handling time[2]	hours	93	147	117
Percent of pre-plant field work time for corn	%	51	79	65

[1]Total equipment operation time.
[2]Total equipment time adjusted for operations that have more than one piece of manure application equipment operating simultaneously.

Iowa has one of the most restrictive manure application windows. Manure slurry application in a corn/soybean rotation requires applying slurry before planting corn in the spring and after soybean harvest in the fall. Spring fieldwork hours prior to corn planting are estimated at 173 hours (Table 4-2). Producer IA-6 needs an estimated 194 hours to land apply manure on a rotational phosphorus limit. Manure application hours exceed the hours available prior to spring planting. This producer would need to purchase additional equipment (not included in our analysis) or hire custom applicators to come in with multiple pieces of equipment or change his cropping system to allow for application during the summer months (e.g. grow wheat in his cropping system). One other IA farmer is able to apply all manure prior to planting because he does have multiple pieces of application equipment. The other IA farmers in the study do not have a significant increase in time needed to apply manure.

Pennsylvania farms had the largest average annual application time of 153 hours. Three of the six modeled farms used multiple pieces of application equipment to reduce the duration of application time. One farm currently does not use multiple pieces of equipment (PA-5) but is estimated to need 309 hours for application. This does not permit application prior to planting corn. Applying manure to fields following wheat harvest may be prohibited because the land is not planted to a crop for several months and nitrogen may volatilize before it can be used. This producer would need to get additional manure application equipment.

4.5.2.3.2 Unagitated Lagoon systems

Agitated lagoon systems are less affected than slurry pit systems by windows of appropriate application time because they often apply effluent via irrigation systems that can apply prior to planting or on top of growing crops. The type of irrigation system is designed for the type of crops that will receive effluent. For example, traveling guns can apply to hays and soybeans with little trouble but are not appropriate for irrigating corn. Pivots would be used if corn is the crop that will receive effluent.

Eighty eight percent of the operations that use lagoons exclusively used irrigation systems (traveling guns, center pivots, spray fields and solid set sprinklers). The two operations that did not use irrigation used dragline systems and were located in Missouri.

For operations using irrigation systems, the switch from a nitrogen rule to a rotational phosphorus rule resulted in an average increase of 18 hours (from 103 to 121), or 17%. The increase was due primarily to the increased time of laying pipe to the irrigation system as the producer irrigated acres further from the lagoon. The increase did not exhaust the number of hours available for applying to growing crops (Table 4-2).

Moving to a rotational phosphorus limit decreased setup time for application for three operations that switched or added traveling gun technology to their existing irrigation system. Two OK farms switched from solid set sprinklers to traveling guns; 1 NC farm added a traveling gun to his spray field in order to reach distant acres. It is safe to say that moving to a phosphorus rule will require most solid set sprinkler systems and spray fields to switch or add a traveling gun to their irrigation equipment.

Twelve percent (2 of 17) of the operations that use lagoons exclusively used dragline systems to land apply effluent. Switching to a rotational phosphorus rule increased application time 90%. One farm (MO-6) now needs 316 hours to apply effluent. According to estimates of field work hours in table 4-2 MO-6 could not apply all his effluent prior to planting corn or soybeans. He would need to apply to wheat stubble in the summer (if permitted) or switch to some other application method.

4.5.2.3.3 Agitated Lagoon systems

We did not model time effects of adopting a phosphorus limit in combination with a requirement to agitate lagoons. The resulting changes in land needs and accessibility and land application feasibility would require a totally different manure application strategy, methodology and equipment on almost all farms. This potential required change was beyond the scope of this study to estimate.

4.5.2.4 Nutrient management planning

We predict a large increase in nutrient management planning time and costs to implement the proposed rules. Nutrient management costs included soil and manure testing, developing a certified nutrient management plan, maintaining records and updating the nutrient management plan. The USEPA clearly intends to have nutrient management plans, including an evaluation of the phosphorus status of the soil, on all land receiving manure from a concentrated animal feeding operation (see Chapter 1). Consequently, we assumed that all land receiving manure would require a nutrient management plan. It is also assumed that the animal feeding operation would incur all the additional cost of nutrient management planning, even on acres not owned or rented by the animal operation. Few farmers will accept manure if they must incur the costs inherent to increased sampling and record keeping. Farmers producing manure will benefit from maintaining complete records on all land areas where they apply manure.

Average nutrient management planning time spent by the farmer was estimated at 104 hours. This is approximately a three-fold increase from the 36 hours currently spent on nutrient management planning.

4.5.2.5 Impact on economics Indicators of Economic Viability After Adopting Phosphorus Limits

The analysis of 31 farms resulted in sales tests (e.g. cost:sales ratio) reported in Table 4-11.

Table 4-11. Cost:sales ratio for nitrogen limit, rotational phosphorus limit and the incremental costs between the nitrogen and rotational phosphorus limits.

Cost:sales Ratio	PAN limits		Rotational Phosphorus Limit		Incremental costs	
	Frequency	Percentage	Frequency	Percentage	Frequency	Percentage
Less than 1%	9	29%	7	23%	17	57%
Less than 2%	6	19%	2	7%	6	20%
Less than 3%	5	16%	5	17%	0	0%
Less than 5%	5	16%	7	23%	1	3%
Less than 10%	5	16%	2	7%	6	20%
More than 10%	1	3%	7	23%	0	0%
Total	31	100%	30	100%	30	100%

The percent of farmers that had cost:sales ratio greater than 5% (defined as moderate impact or financial stress in the USEPA rule) rose from 6 of the 31 farmers (19%) when plant available nitrogen limits were used for manure application to 9 of 30 farmers (30%) when rotational phosphorous limits were implemented. One farm (OK-5) was unable to apply manure under the rotational phosphorus rule (limited to 4 years of phosphorus removal). This farmer raises hogs in the arid southwest and applies pit slurry to hay ground. Under a phosphorus rule, this farmer would not be able to land apply manure. This farmer's dilemma is not included in the cost:sales ratio estimate (i.e. his financial stress is not included in the analysis).

Considering only the incremental costs, as the USEPA does, our analysis estimates six of the remaining 30 farmers are capable of applying manure under a phosphorus rule (20%) with a greater than 5% increase in the sales test. All six are contract producers. Five are in PA and one is in IA. All apply pit slurry with a tanker. Forty-six percent of contract producers are in the stress category.

We predict that the EPA's economic assessment of farms in the moderate to stress categories is underestimated. Table 10-6 of the Preamble (Federal Register, p. 3090) reports that the EPA estimates that 20% of the hog producers will be in the moderate to stress categories. Their estimate of 20% includes the cost of attaining zero discharge. Our estimate of 20% considers only the cost of implementing a rotational phosphorus limit.

We find only producers with pits to be in the moderate and stress categories as defined by the EPA. Chapter 5 will establish that covered, agitated lagoons will have nutrient content similar to pit slurry. Chapter 6 will establish that all farms who adopt covers to meet a "zero discharge" requirement will be in a financial stress category.

We predict that the compliance cost associated with a phosphorus rule (independent from a zero discharge requirement) may have regional implications. PA operations are predominately slurry and need to access an average of six times more acres than they control (own and rent) to apply manure on a P basis. Pit manure distribution via tankers is the most expensive method of land application. All adjacent land was assumed willing to accept the pit slurry. Estimates will be low to the degree that tankers must travel past adjoining land to access more distant land area for manure application.

In the short run, contract farmers with pit slurry will be unable to pay for increased costs of complying with a rotational phosphorus limit from contract payments. Undoubtedly, contracts will be revised to reflect the increased costs of contract producers. However, the multi-year characteristic of production contracts will make the transition difficult for contractors who still have several years remaining on an existing contract.

Additionally, as integrators revise contracts they will seek to minimize costs. One way to minimize costs is to select regions of the country, or even locales within a region, that have low manure management costs. The possibility exists that contractors who built expecting to have contracts for 15 or 20 years will lose their contract due to excessive manure management costs.

Land requirements for applying anaerobic lagoon effluent that were based on nitrogen application require additional acres for phosphorous application, Irrigation systems are difficult to expand on additional land because of topographic and property boundary barriers. Our analysis assumed that additional land for irrigation could be accessed by installing above-ground piping. The additional expense of purchased piping and traveling gun irrigators was factored in to our estimate of the cost of compliance. This estimate is low because it does not consider the expense of clearing a right of way. If a right of way or easement can not be obtained, the producer would probably need to use tankers to transport manure and the expense would be considerably greater than is estimated.

4.5.2.5.1 ROA Analysis

Return on assets (ROA) gives an indication on the impact of regulations on profitability. Our analysis shows that adopting a rotational phosphorus limit reduces average ROA one percentage point – from 20% to 19%. The decrease for contract producers was 1.5 percentage points from 12% to 10.5%.

Adopting a rotational phosphorus rule resulted in an average decrease of manure fertilizer value to the producer of $373/year. The maximum decrease was $17,046 and the maximum increase was $7,409. The largest decreases in value occurred in PA on farms where manure was exported to neighbors' fields. The largest increases in fertilizer value was on farms in IA and NC where additional phosphorus benefit was credited to more controlled acres. Under a phosphorus rule, all nitrogen applied to non-legume crops will be under-supplied and therefore valued. Under a nitrogen rule, phosphorus supplied in excess of crop need is not valued.

4.5.2.5.2 Nutrient Management Planning Costs

One of the major impacts of the proposed rule is the requirement for nutrient management planning consisting of manure and soil sampling and the record keeping requirements to be in compliance with a permit. Using the assumptions published by the EPA for permit nutrient plans we estimated the expense of nutrient management planning (see Section 4.5.2.4).

Nutrient management costs among analyzed operations also increased from an average of $655 to $4,481. Average costs were substantially higher on slurry operations compared to lagoon operations (pits $7,173, lagoon $2,265). Higher land requirements resulted in more acres included in a nutrient management plan. Nutrient management planning costs were a major source of increased cost associated with the proposed rules.

In the short run, our estimate of record keeping cost will be high. We assumed the farm would spread all manure based on phosphorus removal capacity of the crops. Initially many farms may have land capable of using nitrogen-based rates. However, that is likely to change rapidly as phosphorus levels build, particularly on slurry-based operations.

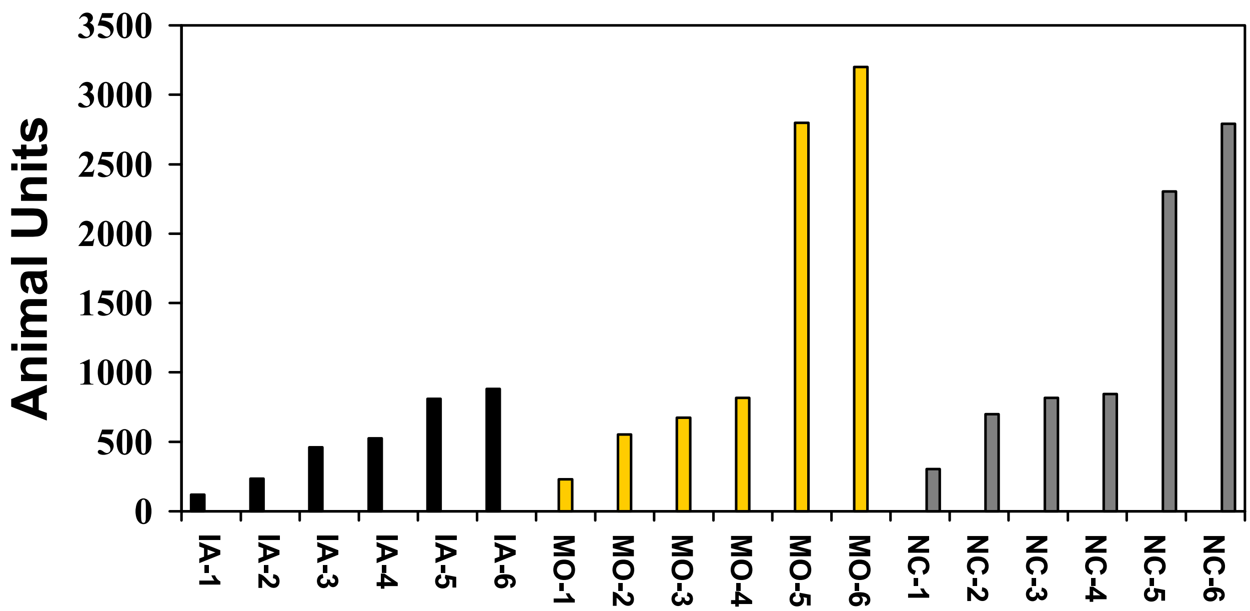
Our analysis of costs indicated an average of 34% of total manure management costs were attributable to nutrient management planning activities. North Carolina had the highest PNP costs per acre of $35/acre because so few acres are used to spread the fixed cost of writing a plan. Iowa and Pennsylvania are able to spread the fixed costs over more acres and have an average PNP cost of $9.50/acre.

4.6 References

Cross, T. L. a. G. M. P. "Depreciation Patterns for Agricultural Machinery." *American Journal Agricultural Economics* 77, no. February(1995): 194-204.

Massey, R. E., et al. (2000) Comprehensive Software for Manure Management Planning, ed. J. A. Moore. Des Moines, IA, American Society of Agricultural Engineers, pp. 468-475.

4.7 FIGURES



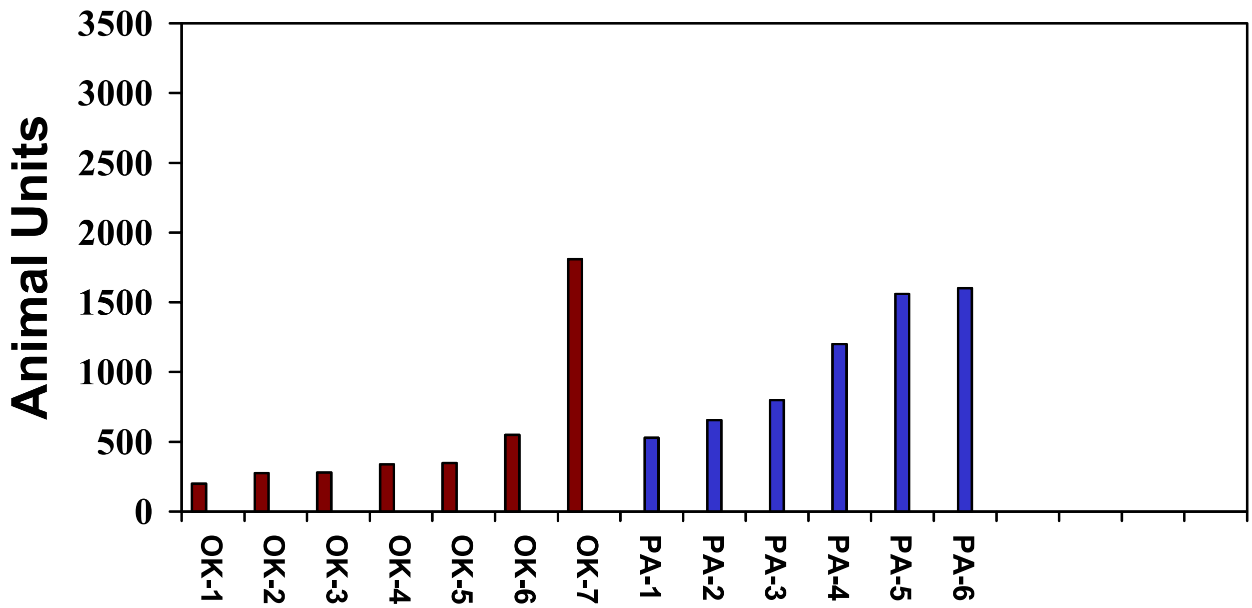


Figure 4-1. Animal units from pigs for 31 operations used in this analysis.

Note: One animal unit was equal to 2.5 pigs greater than 55 pounds or 10 pigs less than 55 pounds.

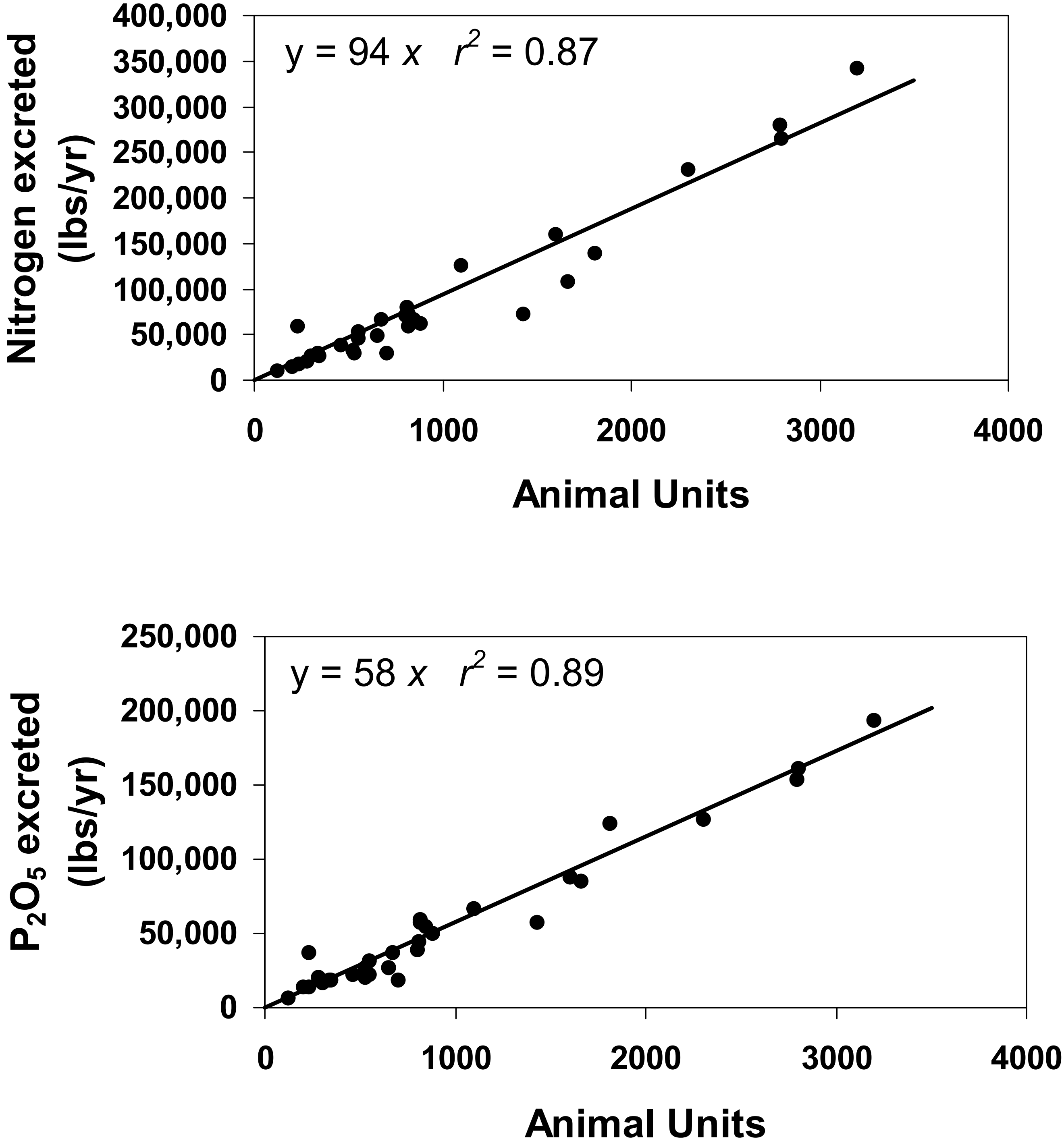


Figure 4-2. The relationship of animal units and estimated nitrogen and phosphorus (as P_2O_5) excreted by pigs on 31 swine operations.

Note: Excreted nutrients were based on estimated feed intake.

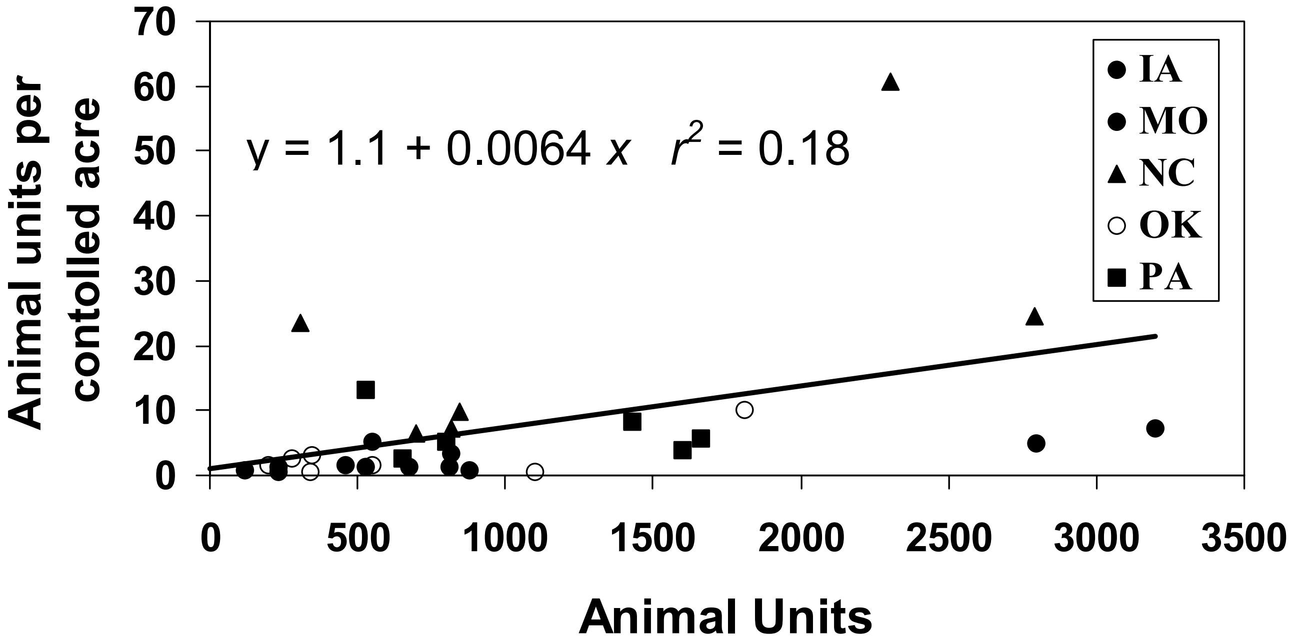


Figure 4-3. Animal units per controlled acre as a function of farm size in animal units.

Notes: Animal units are for pigs on the operation calculated as one animal unit equal 2.5 pigs greater than 55 pounds or 10 pigs less than or equal to 55 pounds. Controlled acres are owned or rented by the animal feeding operation.

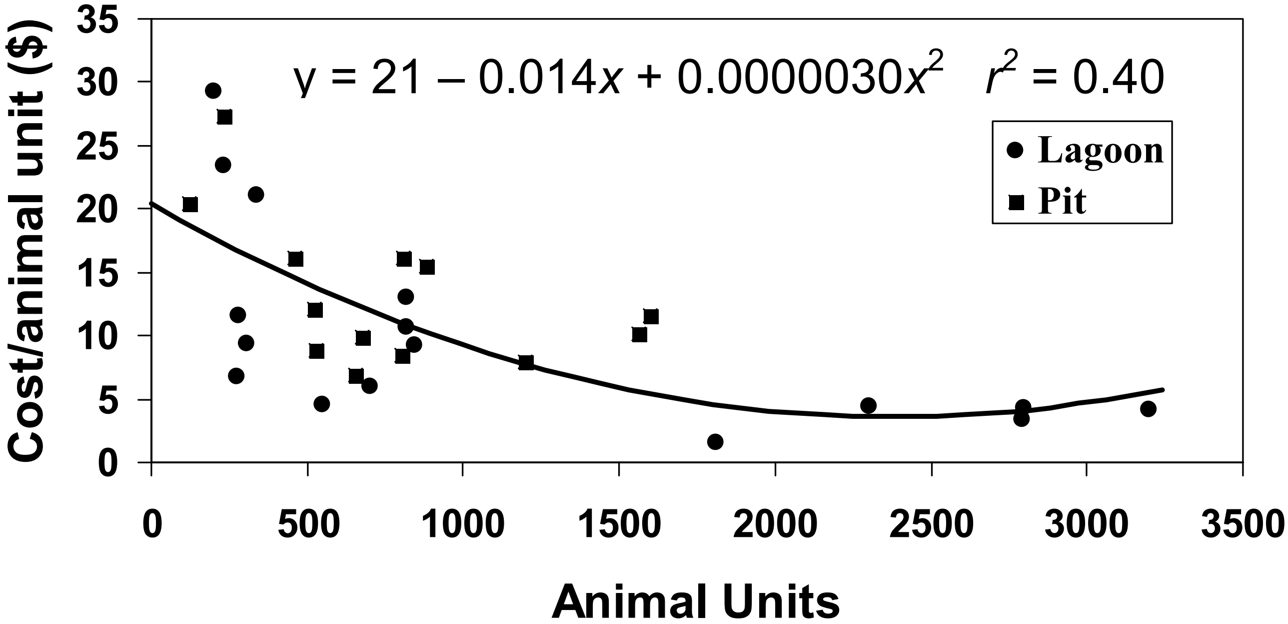


Figure 4-4. Cost of land applying manure per animal unit as affected by size of operation.

Note: Animal units are for pigs on the operation calculated as one animal unit equal 2.5 pigs greater than 55 pounds or 10 pigs less than or equal to 55 pounds.

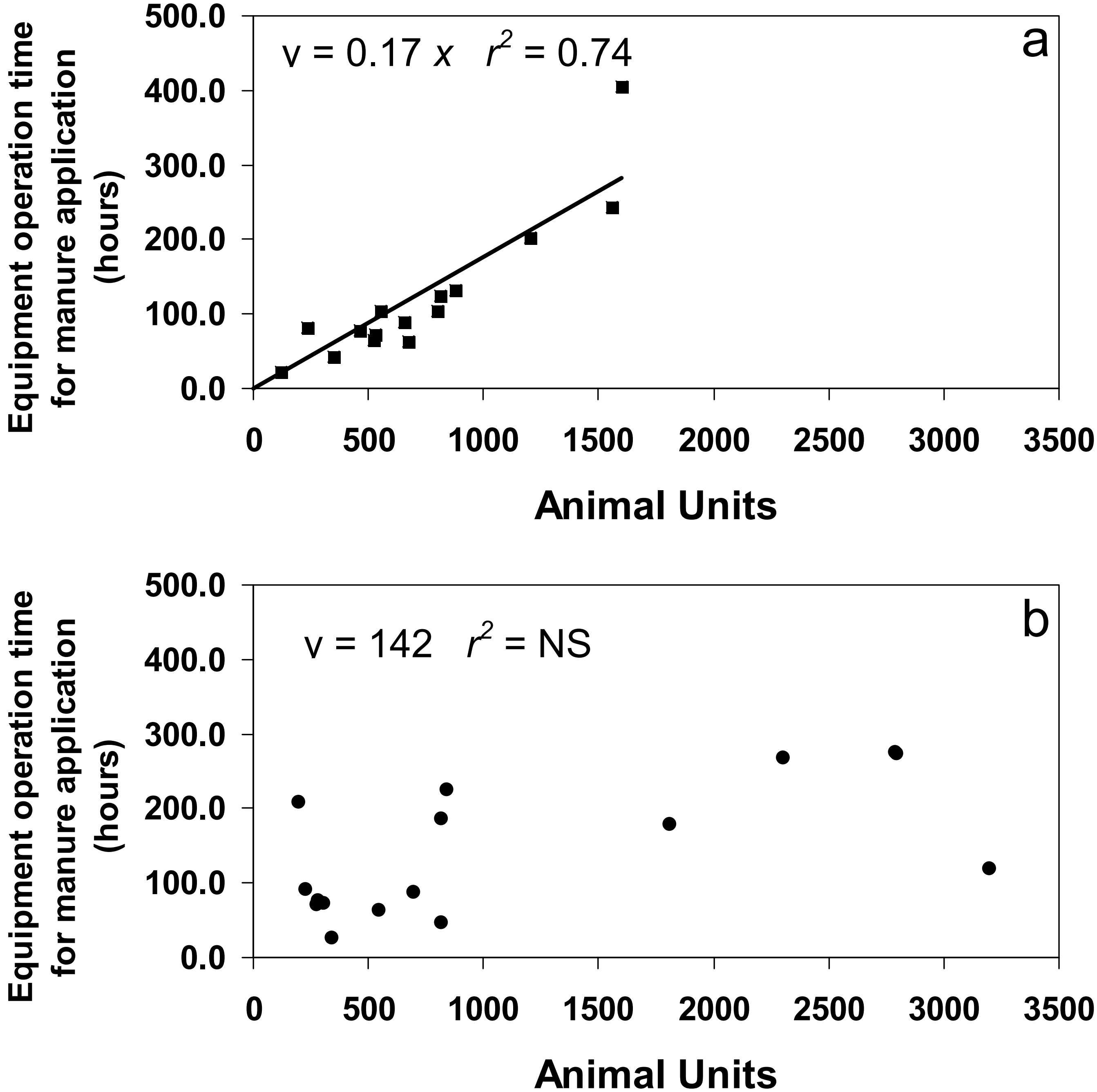


Figure 4-5. Effect of operation size (based on animal units) on total operation time of equipment for manure application. Panel A is for tanker based systems; Panel B is for irrigation based systems.

Notes: Setup, transport and application time included. Animal units are for pigs on the operation calculated as one animal unit equal 2.5 pigs greater than 55 pounds or 10 pigs less than or equal to 55 pounds.

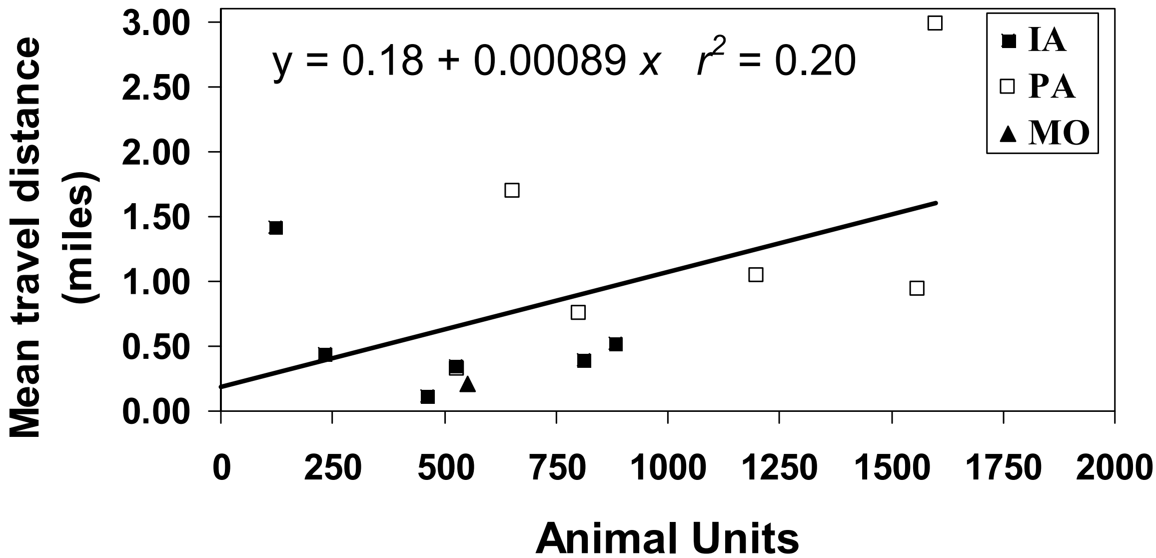


Figure 4-6. Mean travel distance from manure storage to field for nitrogen based manure management as affected by animal units.

Note: Animal units are for pigs on the operation calculated as one animal unit equal 2.5 pigs greater than 55 pounds or 10 pigs less than or equal to 55 pounds.

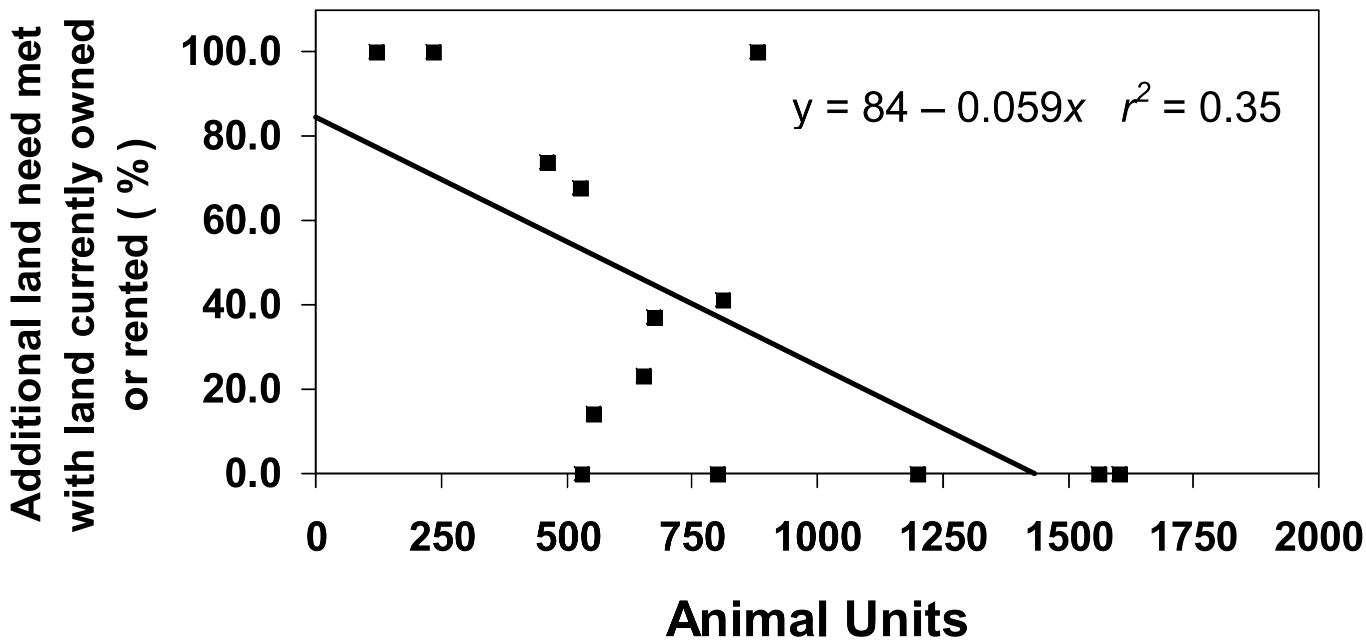


Figure 4-7. For slurry-based operations, the effect of operation size (as animal units) on the additional land need for a phosphorus rule met by land already under control of the animal feeding operation.

Notes: Controlled land is owned or rented by the animal feeding operation. Data is reported as a percent of the total additional acres needed to meet the needs of a phosphorus-based rule. Animal units are for pigs on the operation calculated as one animal unit equal 2.5 pigs greater than 55 pounds or 10 pigs less than or equal to 55 pounds.

4.8 Appendices

4.8.1 Characteristics of Iowa and Missouri Operations

Selected characteristics of 12 swine farms used in this analysis from Iowa and Missouri. Animal units based on 1 animal unit equals 10 pigs less than or equal to 55 pounds or 2.5 pigs greater than 55 pounds. Numbers in parentheses are the number of storage structures of that type on the operation.

ID	Predominant Phases of Production	EPA Animal Units for Pigs	Manure Storage Structures	Application Methodology	Mean Annual Manure Volume (gallons)	Mean Annual Total Nitrogen Available for Land Application (pounds)	Mean Annual Total Phosphorus (as P_2O_5) Available for Land Application (pounds)
IA-1	Nursery	120	Pit, detached	Tanker, tractor; injection	299,715	10,297	6,397
IA-2	Farrow to Wean	234	Earthen storage Pit, attached	Tanker, tractor; surface	1,068,444	21,729	5,928
IA-3	Farrow to finish	461	Pit, detached (2) Solid	Tanker, tractor; injection Box spreader	599,565	37,328	23,523
IA-4	Wean to finish	525	Pit, detached (2) Pit, attached	Tanker, tractor; injection	282,472	32,410	20,009
IA-5	Wean to finish	810	Pit, attached (7)	Tanker, tractor; surface	874,646	79,827	44,353
IA-6	Wean to finish	881	Pit, attached (6) Pit, detached	Tanker, tractor; surface	1,259,616	49,690	43,094
MO-1	Nursery	690	Lagoon, single stage (3)	Traveling gun	1,028,748	55,308	28,413
MO-2	Farrow to finish	552	Lagoon, single stage Pit, attached	Tanker, tractor; injection	898,545	53,148	31,258
MO-3	Wean to finish	675	Earthen storage Pit, attached	Dragline; injection	920,608	66,523	36,962
MO-4	Farrow to wean	818	Lagoon, single stage	Dragline; injection	1,787,886	71,915	58,879
MO-5	Farrow to finish	2798	Lagoon, single stage (2) Lagoon, multi stage	Traveling gun	5,034,473	213,792	161,033
MO-6	Feeder to finish	3200	Lagoon, multi stage	Dragline; injection	3,564,137	341,242	282,181

4.8.2 Characteristics of North Carolina and Oklahoma Operations

Selected characteristics of 13 swine farms used in this analysis from North Carolina and Oklahoma. Animal units based on 1 animal unit equals 10 pigs less than or equal to 55 pounds or 2.5 pigs greater than 55 pounds. Numbers in parentheses are the number of storage structures of that type on the operation.

ID	Predominant Phases of Production	EPA Animal Units for Pigs	Manure Storage Structures	Application Methodology	Mean Annual Manure Volume (gallons)	Mean Annual Total Nitrogen Available for Land Application (pounds)	Mean Annual Total Phosphorus (as P2O5) Available for Land Application (pounds)
NC-1	Nursery	304	Lagoon, single stage	Stationary sprinkler	851,444	12,698	12,542
NC-2	Nursery	700	Lagoon, single stage (2)	Traveling gun	1,236,928	9,884	14,803
NC-3	Farrow to wean	816	Lagoon, single stage	Traveling gun	2,833,339	36,517	39,126
NC-4	Farrow to feeder	844	Lagoon, single stage	Traveling gun	3,076,788	29,458	48,153
NC-5	Feeder to finish	2304	Lagoon, single stage (2)	Traveling gun	4,176,314	83,508	146,100
NC-6	Feeder to finish	2791	Lagoon, single stage	Traveling gun	4,680,769	279,528	153,349
OK-1	Farrow to wean	200	Lagoon, single stage	Stationary sprinkler	2,988,239	14,611	14,122
OK-2	Feeder to finish	275	Lagoon, single stage	Center pivot	2,081,130	82,767	28,739
OK-3	Farrow to wean	280	Lagoon, single stage	Stationary sprinkler	800,507	39,206	26,530
OK-4	Nursery	340	Lagoon, single stage	Traveling gun	318,511	25,217	5,864
OK-5	Farrow to finish	347	Lagoon, single stage (2) Lagoon, multi stage (2)	Traveling gun	444,673	26,517	18,188
OK-6	Nursery	550	Lagoon, single stage	Center pivot	1,797,356	80,085	13,237
OK-7	Farrow to wean	1810	Lagoon, multi stage	Center pivot	4,924,327	257,495	68,001
OK-8[1]	Nursery	600	Lagoon, single stage	Traveling gun	604,033	55,685	28,211

[1]OK-8 used only on zero discharge study.

4.8.3 Characteristics of Pennsylvania Operations

Selected characteristics of six swine farms used in this analysis from Pennsylvania. Animal units based on 1 animal unit equals 10 pigs less than or equal to 55 pounds or 2.5 pigs greater than 55 pounds. Numbers in parentheses are the number of storage structures of that type on the operation.

ID	Predominant Phases of Production	EPA Animal Units for Pigs	Manure Storage Structures	Application Methodology	Mean Annual Manure Volume (gallons)	Mean Annual Total Nitrogen Available for Land Application (pounds)	Mean Annual Total Phosphorus (as P_2O_5) Available for Land Application (pounds)
PA-1	Farrow to finish	528	Pit, attached (2)	Tanker, tractor; surface Tanker, truck, surface	672,434	26,706	29,611
PA-2	Wean to finish	654	Pit, attached	Tanker, truck; surface	804,738	27,248	48,949
PA-3	Feeder to finish	800	Pit, attached	Tanker, truck; surface	854,690	35,042	62,270
PA-4	Feeder to finish	1200	Pit, attached	Tanker, tractor; surface	1,439,615	38,852	58,905
PA-5	Wean to finish	1560	Pit, attached (2)	Tanker, tractor; surface	1,950,710	85,431	107,628
PA-6	Feeder to finish	1600	Pit, attached (2)	Tanker, truck; surface	1,954,808	87,901	160,231