Chapter 2

FEASIBILITY OF ADOPTING PHOSPHORUS-ROTATION LIMITS VERSUS NITROGEN LIMITS FOR MANURE APPLICATION

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2.2 EXECUTIVE SUMMARY

Chapter 2 discusses eutrophication problems that result from excess phosphorus entering surface water. Analyses of phosphorus application strategies that include a phosphorus rotation based approach are presented. These analyses provide a basis for evaluating strategies that allow flexibility in manure application and that are environmentally sound.

Changing from nitrogen based manure application rates to phosphorus limiting application rates requires evaluation of variables that affect the different phosphorus limiting application strategies. Variables evaluated in this study include crop nutrient removal capability; yield variations, soil productivity and manure nutrient concentrations from different manure collection, storage and handling systems. Case study farms were used to evaluate how implementation of manure phosphorus application rate limits would increase land area and manure application time requirements. Results also include effects of the application variables as they influence manure application.

Specific results are listed below:

- This analysis evaluated converting from nitrogen-based application rates to a phosphorus rotation based rate approach where manure is applied based on crop nitrogen need, but where no additional manure is applied until subsequent crops remove the phosphorus.

- Phosphorus limits will have a major impact on producers of crops such as alfalfa and other hays in which the harvested portion of the crop has a high nitrogen to phosphorus ratio.

- Phosphorus limits will also have a major impact on those farmers who produce manure types with low nitrogen to phosphorus ratios such as poultry litter and other solid manure types.

- Regions of the country that have low crop productivity and are dependent on crops that use relatively high amounts of nitrogen compared to phosphorus (e.g. hay crops), will require the greatest increase in land to meet a phosphorus application standard.

- Phosphorus application limits will increase land needed for manure application as much as 900% and as little as 0%, depending on crop removal capabilities and manure characteristics.

- The primary effect on application time for a truck-mounted or tractor-pulled spreader system is the additional travel time required to reach the additional acres required to comply with the phosphorus application rule. Actual land application time increases only if the phosphorus rotation application rate has an upper limit that causes the application rate to be reduced such that the equipment discharge rate must be reduced. No effect on loading time existed because the same volume of manure is being loaded into the same size spreader, regardless of nutrient limit.

- The main potential effect on application time for an irrigation spreading system is the increased setup time required to reach the additional acres required to meet the phosphorus rule. Discharge time and moving the irrigation system between pipe risers has little effect on the time required to irrigate because the manure volume applied is the same as under a nitrogen limit.

- Unagitated lagoon effluent systems will require little additional land under a phosphorus application rule because the effluent typically has a high nitrogen to phosphorus ratio. A requirement to agitate the lagoon will reduce the N:P ratio and increase land requirements for applying the effluent.

2.3 INTRODUCTION

Phosphorus is typically the most limiting nutrient in most freshwater aquatic systems (Sharpley et al., 1994). Increasing the quantity of phosphorus reaching a stream or lake will promote growth of aquatic flora and fauna. Excessive phosphorus will degrade water quality through the process of eutrophication. Negative attributes of eutrophic water bodies include reduced water clarity, excessive algal growth, low oxygen content, altered fisheries, increased filtration costs and objectionable taste for drinking water sources, and in excessively eutrophic waters, water-born toxins from cyanobacteria.

Mismanagement of fertilizers such as manure increases the quantity of phosphorus in runoff from agricultural fields. Increasing soil test phosphorus in a field will increase the concentration of phosphorus in runoff from the field (Pote et al., 1999; Sharpley et al., 1994). Runoff from fields soon after a surface application of phosphorus as chemical fertilizer or manure also results in high phosphorus concentrations in runoff (Daniel et al., 1993; Shrever et al., 1995)

Manure nutrients have been regulated based on the nitrogen content of the manure. Manure application rates could not exceed the annual nitrogen need of the crop. Many manure sources contain more phosphorus and other nutrients than the crop requires when applied based on the nitrogen requirement of the crop. Soil test phosphorus and other soil nutrient tests increase rapidly when these sources of manure are applied every year based on the nitrogen requirement of the crop.

The potential for water quality degradation from mismanagement of manure phosphorus has resulted in voluntary and regulatory efforts to include phosphorus restrictions on manure application rates for agricultural fields. The NRCS agronomy standard (NRCS, 2000) and the proposed EPA rules governing confined animal feeding operations (Federal Register, 01/12/2001) include provisions that manure be applied based on the phosphorus removal rate of the crop. In both standards, phosphorus status of the soil is assessed by one of three methods: the phosphorus index, the phosphorus threshold or the soil test phosphorus level. Manure can be applied every year based on the annual nitrogen requirements of the crop to fields with a low or medium rating in accordance with the chosen assessment method. Phosphorus and nitrogen limits must be observed on fields with a high rating by the selected assessment method. No manure applications are allowed on fields rated very high.

Phosphorus-based strategies for manure application

There are at least two potential strategies for implementing phosphorus limits for manure application. Phosphorus rotation is the term we use to describe the practice of applying more than one year of phosphorus to a soil and then not applying manure until an equivalent amount of phosphorus has been harvested from the field as crops, meat or milk. In a nitrogen-based phosphorus rotation approach, manure is applied to the crop based on the nitrogen needs of the crop. After a manure application based on nitrogen, no additional manure is applied until an equivalent amount of phosphorus has been harvested from the field by crops, meat or milk. A nitrogen-based phosphorus banking strategy allows the farmer to apply manure to a field at the same rate he has in the past, but requires that he reduce the number of times manure is applied to a specific field. A farmer using a nitrogen-based phosphorus banking strategy will be able to use the same land-application equipment, pumping rates and application speeds as were previously used for nitrogen-based management.

Alternatively, phosphorus could be limited to the annual crop needs of the crop. In this strategy, crop phosphorus removal capacity will be met each year with a manure application. However, the manure will frequently provide insufficient nitrogen to meet crop needs and additional fertilizer nitrogen may be required each year. Many farmers adopting annual phosphorus limits will likely need to reduce manure application rates.

In Chapter 3 we detail the benefits of the nitrogen-based phosphorus rotation method compared to the annual phosphorus limit approach. Benefits of the phosphorus rotation strategies include: 1) allowing the farmer to continue to use the same equipment to apply manure and 2) the ability to use manure to meet the full fertilizer need of the crop in years manure is applied, thus increasing the value of the manure and reducing fertilization costs on fields receiving manure.

Constraining farmers to apply only one year of manure phosphorus per pass of the manure spreader will result in greater costs. This is due to more time being needed for manure application and for new equipment or modifications to existing equipment to attain lower manure application rates. These costs will affect most farmers applying manure with a low nitrogen to phosphorus ratio (e.g. poultry litter and swine slurry) to crops with a high nitrogen to phosphorus ratio (e.g. alfalfa and bermuda grass). Operators applying unagitated swine lagoon effluent will likely be unaffected by the type of phosphorus rule because of its high nitrogen to phosphorus ratio.

The effluent limitation guideline proposed by the EPA explicitly prohibits phosphorus banking strategies to meet phosphorus application limits (“Multi-year phosphorus applications are prohibited when either the P-index is rated high, the soil phosphorus threshold is between ¾ and 2 times the threshold value, or the soil test phosphorus level is high…”; Federal Register, 1/12/2001, pg. 3142). If the rule is adopted as proposed, the analysis in this chapter will underestimate costs and not address infeasibility issues associated with annual phosphorus limits contemplated by the EPA.

We chose to evaluate the phosphorus rule based on its least restrictive form, the phosphorus rotation approach. We based our analysis on the nitrogen-based phosphorus rotation limit because that is the most feasible and least expensive of the two approaches to a phosphorus rule. If the USEPA chooses to implement the annual phosphorus limit, the total costs of the proposed EPA approach would be the sum of incremental costs developed here for conversion from nitrogen-based applications to nitrogen-based phosphorus rotation approach plus the incremental costs developed in Chapter 3 associated with conversion from a nitrogen-based phosphorus rotation approach to an annual phosphorus limit.

This chapter evaluates removal capacity of selected crops throughout the U.S. and determines anticipated annual phosphorus application rates for selected classes of manure. These application rates were then compared to the technical specifications of selected, currently available land application equipment.

2.4 MATERIALS AND METHODS

The top concentrated livestock producing states (Table 2-1) were identified based on being in the top ten states according to the 1997 Census of Agriculture in at least one of the following six categories of animal feeding operations (NASS, 1997): dairy (*Bos taurus*), cattle fatted on grain, pig (*Sus scrofa*) inventory, layers (*Gallus domesticus*), broilers or turkeys (*Meleagris gallopavo*). States included were Alabama, Arkansas, California, Colorado, Delaware, Georgia, Iowa, Idaho, Illinois, Indiana, Kansas, Maryland, Michigan, Minnesota, Missouri, Mississippi, North Carolina, Nebraska, New York, Ohio, Oklahoma, Pennsylvania, South Carolina, South Dakota, Texas, Virginia, Washington and Wisconsin.

We estimated the range of typical yields for the 28 major concentrated livestock states for the crop categories corn (*Zea mays*), corn silage, soybean (*Glycine max*), wheat, alfalfa (*Medicago sativa*) and other hay based on state mean yields between 1990 and 1999 (NASS, 2000). The state with the minimum 10-year mean yield, the state with the maximum 10-year mean yield and the 28-state mean yield and standard deviation of the selected states were identified (Table 2-2). Some crops were not grown in significant quantities in all states (NASS, 2000), so for these crops fewer than 28 states were included in the analysis.

Nitrogen and phosphorus removal capacity of the harvested portion of the crop were developed through literature review for the selected crops (Table 2-3). These were used to calculate nitrogen and phosphorus removal rates for minimum, maximum and mean yields for each crop where:

$$\text{nutrient removal} = \text{yield} \times \text{removal capacity}/\text{yield unit} \qquad \text{Eq. 2-1}$$

Phosphate removal capacity of the other hay category (cool and warm season grasses) was based on 12 lb P_2O_5/ton.

Typical nutrient concentrations for selected types of manure were developed through a literature review (Table 2-4). Manure was divided into two categories, liquid (slurry and lagoon effluent) and solid. Nutrient concentrations in liquids were reported as lbs/1000 gallons and nutrient concentrations in solids were reported as lbs/ton. Nutrient concentration was also reported as percent nutrient concentration where liquid manure was assumed to have a density of 8.3 lb/gal.

Table 2-1. States ranking in top 10 of livestock production.

State	Hogs	Dairy	Cattle on Feed	Broilers	Turkeys	Layers
AL				3		4
AR				2	5	3
CA		1	7	8	6	6
CO			4			
DE				9		
GA				1		1
ID	4					
IN	6				7	7
IA	1		5			10
KS	10		2			
MD				7		
MI		9				
MN	3	5	10		2	
MS				5		
MO	7				3	
NE	5		3			
NM		10				
NY		3				
NC	2			4	1	9
OH	9					2
OK	8		6			
PA		4			10	5
SC					8	
SD			8			
TX		6	1	6	9	8
VA				10	4	
WA		8				
WI		2				

Source: (NASS, 1997)

Note: Values in each column are the ranking of the state in each of the 6 categories; blanks indicate the state is not in the top ten states in that category.

Plant available nitrogen was estimated by assuming 65% of the organic nitrogen (75% for poultry manure) was available to the crop, and 60% (surface applications) or 100% (injected manure) of the NH4-N was available to the crop. Crop need for phosphorus was estimated based on crop removal capacity of the crops in the rotation. Manure phosphorus was assumed to be 100% available. Manure application rates were limited by the lesser of nitrogen requirement of the crop in the year of application or the 4-year phosphorus need of the crop rotation. After the 4-year phosphorus need of the rotation was met with manure applications no additional manure was applied to a field until crop removal had removed the applied phosphorus. This approach was designated as the nitrogen-based phosphorus rotation approach.

Manure application rate of selected land application technologies was calculated using the equation:

$$\text{Application rate} = \frac{\text{discharge rate}}{\text{travel speed} \times \text{effective swath width}} \qquad \text{Eq. 2-2}$$

For liquid manures application rate was calculated in gallons/acre; for solid manure it was calculated in tons/acre.

Table 2-2. Mean, standard deviation of the mean, minimum and maximum mean state yields of selected crops among states ranking in the top 10 in livestock production.

Crop	n	Yield Units	Mean Yield	Std. Dev.	Max. Yield	Top 5 States	Min. Yield	Bottom 5 States
Corn grain	28	bu/ac	117	25.0	185	WA, CA, CO, ID, KS	72	SC, AL, NC, SD, GA
Corn silage	28	tons/ac	15	4.2	26	WA, CA, ID, CO,TX	8	SD, AL, SC, MS, MO
Soybean	23	bu/ac	32	6.8	43	IA, IN, IL, WI, NE	22	SC, GA, OK, AL, MS
Wheat	28	bu/ac	49	12.0	78	ID, CA, WA, DE, OH	29	OK, TX, SD, MN, CO
Alfalfa	24	tons/ac	3.6	0.9	6.8	CA, WA, TX, ID, KS	2.3	SD, NY, WI, NC, MO
Other hay	28	tons/ac	2.1	0.4	2.8	CA, DE, WA, GA, IN	1.3	NE, SD, OK, CO, PA

Note: Yield data are based on state mean yields between 1990 and 1999 (NASS, 2000).

Table 2-3. Nutrients removed in the harvested portion of selected crop[1].

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).

[1] Sources:

NRCS. 1992. Agricultural waste management handbook. U.S. Department of Agriculture Soil Conservation Service, Washington DC.
Buholtz, D.D. 1992. Soil Test Interpretations and Recommendations Handbook, Department of Agronomy, University of Missouri, Columbia, MO.
Potash Phosphate Institute, Norcross, GA.
Agronomy Guide, The Pennsylvania State University, State College, PA.
North Carolina State University, AG-439-16
General Guide for crop nutrient recommendations. March 1999. Iowa State University, Ames, IA.
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

Table 2-4. Typical nutrient concentration in selected sources of manure[1].

						PAN:P_2O_5 Ratio	
Manure Source	Units	Total N	NH_4-N	P_2O_5	K_2O	Surface-applied	Injected
Pigs							
Grow finish - deep pit	lb/1000 gal	50	33	42	30	0.73	1.04
Grow finish - wet/dry feeder deep pit	lb/1000 gal	75	50	54	40	0.86	1.23
Grow finish - earthen pit	lb/1000 gal	32	24	22	20	0.89	1.33
Farrow-finish pit	lb/1000 gal	28	16	24	23	0.73	0.99
Nursery pit	lb/1000 gal	25	14	19	22	0.82	1.11
Grow-finish unagitated lagoon	lb/1000 gal	4.0	4.0	2.0	3.0	1.20	2.00
Farrow-finish unagitated lagoon	lb/1000 gal	4.5	4.0	2.9	3.6	0.94	1.49
Grow finish - solid	lb/ton	16	6	9	5	1.12	1.39
Farrow finish - solid	lb/ton	14	6	8	5	1.10	1.40
Nursery - solid	lb/ton	13	5	8	4	1.03	1.27
Dairy cows							
Pit	lb/1000 gal	31	6	15	19	1.32	1.48
Unagitated lagoon	lb/1000 gal	4.1	3.6	1.7	2.9	1.46	2.31
Solid	lb/ton	10	2	3	7	2.13	2.40
Beef cows							
Finish - pit	lb/1000 gal	29	8	18	26	1.03	1.20
Finish - solid	lb/ton	11	4	7	11	0.99	1.22
Feedlot solid	lb/ton	24	-	16	3	-	-
Feedlot lagoon sludge	lb/1000 gal	52	-	18	14	1.88	1.88
Poultry							
Broiler litter	lb/ton	71	12	69	47	0.75	0.82
Broiler breeder litter	lb/ton	37	8	58	35	0.46	0.51
Turkey litter	lb/ton	55	12	63	40	0.63	0.70
Turkey breeder litter	lb/ton	35	8	47	18	0.53	0.60
Layer - solid	lb/ton	34	12	51	26	0.46	0.56
Layer - pit	lb/1000 gal	57	37	52	33	0.72	1.00
Layer lagoon liquid	lb/1000 gal	27	23	7.1	42	2.37	3.66
Layer lagoon sludge	lb/1000 gal	84	26	308	40	0.19	0.23
Layer under cage	lb/ton	28	14	32	20	0.59	0.77

Notes: All values are on an “as-is” or wet basis. Plant available nitrogen (PAN) estimates the fertilizer value of manure when surface applied or injected.

[1] Sources:

MWPS. 2000. Manure Characteristics. Midwest Plan Service, 122 Davidson Hall, ISU, Ames IA.

NRAES-132. 1999. Poultry waste management handbook. Natural Resource, Agriculture, and Engineering Service, Ithaca, NY.

NRCS. 1992. Agricultural waste management handbook. U.S. Department of Agriculture Soil Conservation Service, Washington DC.

2.5 RESULTS AND DISCUSSION

2.5.1 Proportional increase in land requirements

Manure and harvested crop characteristics determine the percent increase in land requirements of a farmer converting from an annual nitrogen-based application rate to a phosphorus-based application rate. The percent increase in acres needed if adopting a phosphorus rule (P_{INC}) is a function of the N:P_2O_5 ratio of both the crop fertilizer need and the manure where:

$$P_{inc} = \left(\frac{\text{crop fertilizer N}:P_2O_5 \text{ ratio}}{\text{manure PAN}:P_2O_5 \text{ ratio}} - 1 \right) \times 100\,\% \qquad \text{Eq. 2-3}$$

This calculation assumes that the land currently receiving manure and the additional land have similar crops and fertilizer needs and manure is currently applied based on the nitrogen need of the crop. Alternatively, the percent decrease in manure application rate (R_{DEC}) when transitioning from a nitrogen-based rate to a phosphorus-based rate is:

$$R_{DEC} = \frac{\text{manure PAN}:P_2O_5 \text{ ratio}}{\text{crop fertilizer N}:P_2O_5 \text{ ratio}} \qquad \text{Eq. 2-4}$$

The N:P_2O_5 ratio of crops typically is greater than the PAN:P_2O_5 ratio of manure (compare Tables 2-3 and 2-4). Harvested crops typically have a N:P_2O_5 ratio of 1.8 to 4.2 (Table 2-3). Manure PAN:P_2O_5 ratios range from 0.5 to almost 5 although most are below 1.5 (Table 2-4). Farmers adopting a phosphorus limit under typical conditions will need to reduce per acre manure application rate and increase acreage receiving manure. For example, a farmer converting to a phosphorus limit would need to increase acres for manure application by 220% (using Eq. 2-3, ((2.3/.73)-1) x 100) if surface-applying finishing pig slurry to corn. Only injected lagoon effluent consistently exceeded some crop N:P_2O_5 ratios. In these situations, nitrogen, not phosphorus, will limit manure application rates, and there will be no increase in land requirements.

The harvested components of all crops have a greater fertilizer nitrogen need or nitrogen removal capacity than phosphorus removal capacity (N:P_2O_5 ratio > 1; Table 2-3). Crops with the highest fertilizer nitrogen need compared to phosphorus need (highest N:P_2O_5 ratios) will be most affected by conversion to a phosphorus standard. Soybean, bermuda grass and alfalfa hay had the highest reported N:P_2O_5 removal ratios for the harvested portion of the crop (Table 2-3). Crops with higher phosphorus need compared to nitrogen, or fields needing phosphorus in excess of crop phosphorus removal, will be less affected by conversion to phosphorus removal-based rates.

Manure types with the lowest PAN:P_2O_5 ratio will be more affected by conversion to an phosphorus standard. Manure nitrogen available to the crop (PAN), not total nitrogen content of the manure, is the critical component. Consequently, surface applied manure is more affected by conversion to phosphorus application rates than injected manure because losses during surface application of manure reduce the manure PAN:P_2O_5 ratio.

Adopting phosphorus-based limits on application rates will require increasing land requirements for manure by up to a factor of 10 (Fig. 2-1). Manure has a greater range in PAN:P_2O_5 ratios compared to the N:P_2O_5 of crops (compare Tables 2-3 and 2-4). Therefore, differences among manure types and management cause the greatest range in increased acres required when adopting a phosphorus application rule. The largest increases are associated with solid manure such as poultry litter (e.g. up to a 900% increase acres when applied to soybean or hay). Increased acreage need for surface applications of slurry manure and unagitated lagoon effluent can exceed 350% on the same crops. Phosphorus-based application for some injected lagoon effluents will only require an increase in land of 15% for soybean and hay production.

The N:P_2O_5 ratios of the harvested portion of crops only vary by a factor of approximately 2 (Table 2-3). Consequently, potential increases in land need due to crop factors are less than those due to manure factors. For example, among poultry litter sources, phosphorus rates would require 220 (wheat) to 520% (alfalfa) more land. Similarly, among unagitated pig and dairy lagoon manure sources, phosphorus rates would require increasing land base by 60 to 250% (surface applied) and 0 to 120% (injected), depending on the crop produced.

In summary, phosphorus-based rates will result in increased land requirements for most animal producing farms. The proportional increase in acreage requirements is independent of crop yield or quantity of phosphorus produced by the animals. Phosphorus limits will have the largest impact on producers dependent on crops such as alfalfa and other hays where the harvested portion of the crop has a high N:P_2O_5 ratio. Phosphorus limits also will have the largest impact on manure types that have lower PAN:P_2O_5 ratios such as poultry litter and other solid manure types.

2.5.2 Quantity of additional land required

The additional acres a farmer needs to comply with a phosphorus rule (A_{INC}) is a function the quantity of phosphorus an operation land applies (P_{LA}) and the quantity of phosphorus a crop requires per acre (P_{CR}) where:

$$\mathrm{A}_{\mathrm{INC}} = \frac{PAN}{P_{CR} \times \left(1 - \left(\frac{manure\ PAN : P_2O_5}{crop\ N : P_2\,O_5}\right)\right)} \qquad \text{Eq. 2-5}$$

Any operational characteristics that increase phosphorus in the manure will increase the number of acres needed to meet a phosphorus rule (Eq. 2-5). Larger operations will need access to more acres to comply; operations that have slurry systems or agitate lagoons will have a greater increase in required acres when adopting a P rule than operations that apply unagitated lagoon effluent. At least 85% of the phosphorus entering an unagitated lagoon is retained in the sludge that remains in the bottom of the lagoon (MWPS, 2000). Consequently, these systems will require 85% fewer additional acres when converting to a phosphorus rule than a slurry system that applies all excreted phosphorus every year.

The productivity of the cropland receiving manure also has a significant impact on the amount of additional acres a farmer will need to comply with a phosphorus rule (Eq. 2-5). There is a wide range in soil productivity in the top animal feeding states (Table 2-2). States with the highest yields have mean yields that are 2 (soybean) to 3.25 (corn silage) times greater than the lowest yielding states. This means that under a phosphorus rule, the low crop productivity states will require 2 to 3.25 times more land to distribute the same quantity of phosphorus. For example, an average operation in South Carolina has lower yield potential for corn grain than one in Washington State (Table 2-2). The South Carolina operation would require 340 additional acres of land to adopt a phosphorus rule for a 1000-head finish swine operation that annually injects approximately 18,000 lbs of P_2O_5 as slurry. A similar operation in Washington State generating the same quantity of P_2O_5 would only require 130 additional acres of land. Both operations need to increase their land base by 120%, (((2.3/.73)-1) x 100, Eq. 2-3). The less productive soils require nearly 3 times more land to meet the requirements for a phosphorus rule.

Less productive soils also have greater risk for large swings in land requirements than more productive soils. The yields reported in Table 2-2 are 10-year means. In some years, yields can be substantially lower due to poor weather and other conditions. Following these years, farmers will need to access additional land for manure application. The per acre crop yield and phosphorus removal capacity is inversely related to the number of acres required (Eq. 2-5). Small changes in yield goal make a larger impact on the number of acres needed on low yielding sites than on high yielding sites (Fig. 2-2). A 5% drop in crop yield for a 1000-head swine finishing operation would require the owner to locate 70 acres of additional land in the South Carolina example, but only 29 acres in the Washington State example.

Regional cropping patterns, manure management systems and soil productivity will determine the regions of the U.S. most impacted by conversion to a phosphorus rule. The effect of manure type, cropping system and yield capacity of the land can combine to create vastly different impacts on the land requirements of a phosphorus rule for operations handling the same quantity of phosphorus. For example, a poultry operation that has dry litter containing 18,000 lbs of P_2O_5 (approximately 35,000 birds) and a PAN:P_2O_5 ratio of 0.75 applying manure to bermuda grass hay with a yield goal capacity of 2 tons/acre will require 680 acres of additional land to meet the requirements of phosphorus-based land application. A 1000-head swine finishing operation using a pit-slurry system generates a similar amount of P_2O_5. If either operation applies slurry to corn with a yield goal of 185 bu/acre, 70 acres of additional land will be needed. A swine finishing operation injecting unagitated lagoon effluent for wheat production may require no additional land for manure application because nitrogen, not phosphorus, limits land application rates for that manure source on wheat. The areas with the greatest potential impact will be those areas that already grow crops with low capacity to remove phosphorus (e.g. hay, Table 2-2), and those that have soils with limited productivity. These regions already require the most land to meet the current nitrogen requirements for land application and they will also require the largest increase in acreage to meet phosphorus-based acreage requirements for land application of manure.

Unagitated lagoons create a unique situation with respect to the adoption of phosphorus application limits. Until now, we have assumed that conversion from a nitrogen-based to a phosphorus-based rule would require application of the manure currently removed annually from the manure storage. Lagoon systems partition at least 85% of the phosphorus into the sludge, which remains in the lagoon after pumping unagitated effluent from the surface of the lagoon (MWPS, 2000). The lagoon effluent has a relatively high PAN:P_2O_5 ratio if it is injected into the soil, thereby minimizing ammonia nitrogen volatilization. If the phosphorus in the sludge is not accounted for, conversion to a phosphorus rule requires little adjustment for an operation that pumps from an unagitated lagoon. The analysis above addresses this scenario. Operations with anaerobic lagoons will need much larger increases for land application if lagoons must be agitated or other phosphorus accountability is required to meet a phosphorus rule. This topic is dealt with in greater detail in Chapter 4.

In summary, the amount of phosphorus generated by the farm, the productivity of the land, and the nitrogen to phosphorus ratios of the crop and the manure all affect the quantity of additional acres a farm would require to adopt a phosphorus rule. Regions of the country that have low crop productivity, and are dependent upon crops that use relatively high amounts of nitrogen compared to phosphorus (e.g. hay crops) will require the greatest increase in land to meet a phosphorus standard. Operations with manure that has a low PAN:P_2O_5 ratio such as solid and slurry manure will also be required to have greater land application areas to implement phosphorus rules. The effect of these factors can be large. For an operation that generates 18,000 lbs P_2O_5 annually, the added amount of additional land required for a phosphorus rule can range from 0 to more than 650 acres.

2.5.3 Time Effects Model

The objective of this section is to develop and evaluate equations describing the component activities of land application of manure. This analysis assumes that if a phosphorus rule is adopted, producers will be able to use a phosphorus rotation approach. A phosphorus rotation approach means they will be allowed to apply manure to meet the nitrogen needs of a crop and then refrain from additional manure applications on that field until crop removal depletes the excess phosphorus. This will result in an manure application pattern where manure will be applied to one set of fields the first year, a second set the next year and so on until crop removal of phosphorus allows a return to the first set of fields.

An annual phosphorus limit where manure applications cannot exceed the yearly phosphorus need of the crop was proposed by the USEPA (FR, 2001; page 3142). In Chapter 3 and 4, the feasibility and cost issues of the annual approach are addressed. We chose to evaluate phosphorus-based management using the phosphorus rotation approach in this chapter because of the infeasibility and increased cost of adopting the annual approach on many farms.

2.5.3.1 Truck-mounted and tractor-pulled spreaders

Total time needed for land application of manure for tractor-pulled and truck-mounted spreaders (T_{TOT}) is a function of loading time (LT), road travel time to the field (TT_R), in-field travel time to the point where spreading/injection begins and after spreading/injection ceases (TT_F), and discharge time (DT) where:

$$\mathrm{T_{TOT} = LT + TT_R + TT_F + DT} \qquad \text{Eq. 2-6}$$

In this analysis, we are assuming that the farmer can apply manure at the same rate under the phosphorus rule as under the nitrogen rule in the years a field receives manure. Consequently, the farmer will be using the same equipment to haul the same number of loads of manure each year under the phosphorus rule as under the nitrogen rule. The primary change will be that the farmer may need to make applications to different fields in different years.

Loading time (LT) should not change because the same equipment is being used to pump similar amounts of manure with both strategies. Discharge time (DT) should not change between nitrogen-based and phosphorus-based land application approaches. Manure is being applied at the nitrogen-based need on all crops receiving manure in a given year under both scenarios. This result assumes additional acres needed for phosphorus-based applications have the same fertilizer needs as acres currently being used.

In-field travel time (from the field gate to the point of application and back) (TT_F) also should remain relatively constant between the nitrogen-based and phosphorus rotation-based approaches. This result also assumes that the additional fields needed to comply with the phosphorus rule are similar to the fields currently used for manure application.

Conversion to a phosphorus rotation-based phosphorus limit can have significant effects on road travel time (TT_R). Road travel time (TT_R) for tanker spreaders is a function of total distance traveled on the road to and from all fields receiving manure (D_{TOT-R}), road travel speed (MTS_R) where:

$$\mathrm{TT_R} = D_{TOT-R} \times MTS_R \qquad \text{Eq. 2-7}$$

A convenient way to calculate TT_R is:

$$\mathrm{TT}_{\mathrm{R}} = NOL \times AMDPT \times MTS_R \qquad \text{Eq. 2-8}$$

where NOL is number of loads per year and AMDPT is the annual mean distance per trip. A farmer applying manure to the same fields every year should find that AMDPT remains relatively constant from year to year.

When adoption of the phosphorus rule requires access to additional land for manure application, there is a potential for AMDPT to increase. It is possible that as more land is required for manure application, the farmer will have to travel longer distances to reach that land. However the specific effects of the phosphorus rule on travel time will be highly site specific depending upon the current amount of road time spent reaching fields receiving manure and the location of the additional land used to meet the new requirements of the phosphorus rule. The incremental increase in road travel time (TT_{R-INC}) will be:

$$\mathrm{TT}_{\mathrm{R-INC}} = \left(\mathrm{AMDPT}_{\mathrm{P-Rule}} - AMDPT_{current}\right) \times NOL \times MTS_R \qquad \text{Eq. 2-9}$$

where $AMDPT_{P-RULE}$ is the average mean distance per trip under the new rule and $AMDPT_{current}$ is the average mean distance per trip under current conditions.

Note that incremental changes in annual mean distance per trip will be magnified in total road travel time because the changes are multiplied by the number of loads per year. Operations where $AMDPT_{P-RULE}$ is much larger than the current value and where there is a high annual NOL will see large increases in time required for manure application under a phosphorus rule.

There is a potential for the additional road travel time to make conversion to phosphorus-based application rates infeasible using the current manure application equipment complement. Operations that have a large increase in AMDPT may not have sufficient time to land apply manure during manure application windows and/or may have unrealistic work loads for existing tractors and spreaders. These operations would need to invest in additional or larger applicators or supplemental equipment such as nurse tanks to reduce road travel time.

2.5.3.2 Traveling gun and dragline systems

Total time needed for land application of manure (T_{TOT}) for traveling guns and dragline systems that use an irrigation piping network for transport of manure is a function of irrigation network setup time (INST), between pull setup time (BPST) and discharge time (DT) where:

$$\mathrm{T}_{\mathrm{TOT}} = \mathrm{INST} + \mathrm{BPST} + \mathrm{DT} \qquad \text{Eq. 2-10}$$

Note that many operators will do much of the work associated with INST while manure is being applied at another location, thereby reducing the duration of manure application activities but not the total labor and time required to accomplish the task.

This analysis assumes the farmer can apply manure at the same rate under the phosphorus rule as under the nitrogen rule in the years a field receives manure. Consequently, the farmer will be using the same pumping and irrigation equipment to pump the same volume of manure each year under the phosphorus rule as under the nitrogen rule. The primary change will be that the farmer may need to apply on different fields in different years.

Between pull setup time (BPST) should not change because the same equipment is being used to pump similar amounts of effluent with both strategies; the number of pulls should only change if the geometry of the additional fields is significantly different on the additional fields needed for land application. Discharge time (DT) should not change between nitrogen-based and phosphorus-based land application approaches. Manure is being applied at the nitrogen-based need on all crops receiving manure in a given year under both scenarios. This result assumed additional acres needed for phosphorus-based applications have the same fertilizer needs as acres currently are being used.

Irrigation network setup time (INST) is analogous to road travel time in tanker systems; it has the potential to increase with adoption of a rotation-based phosphorus limit. It is possible that as more land is required for manure application, the farmer will have to pump effluent greater distances to reach that land. The specific effects of the phosphorus rule on set-up time will be highly site specific.

Access to additional land is often difficult for irrigation-based systems. Existing pumps and piping have absolute limits on effective pumping distances. Usually additional pipe is required to reach more distant acres and larger pumps or booster pumps are also needed. Piping manure to more distance sites may not be possible due to natural or man-made barriers that block access to additional land application areas. The inability to obtain easement access for piping across non-owned land not controlled by the farmer can also limit the additional acres available for irrigation of manure effluent.

2.6 REFERENCES

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2.7 FIGURES

The figures for this chapter are on the following pages.

Figure 2-1. The percent increase in acres needed for adopting a phosphorus-based rule and the percent over-application of phosphorus when manure is applied at a nitrogen rate for selected crops and manure sources. Values of 0% will continue to be restricted by nitrogen limits and have no excess phosphorus applied when applied at nitrogen limited rates.

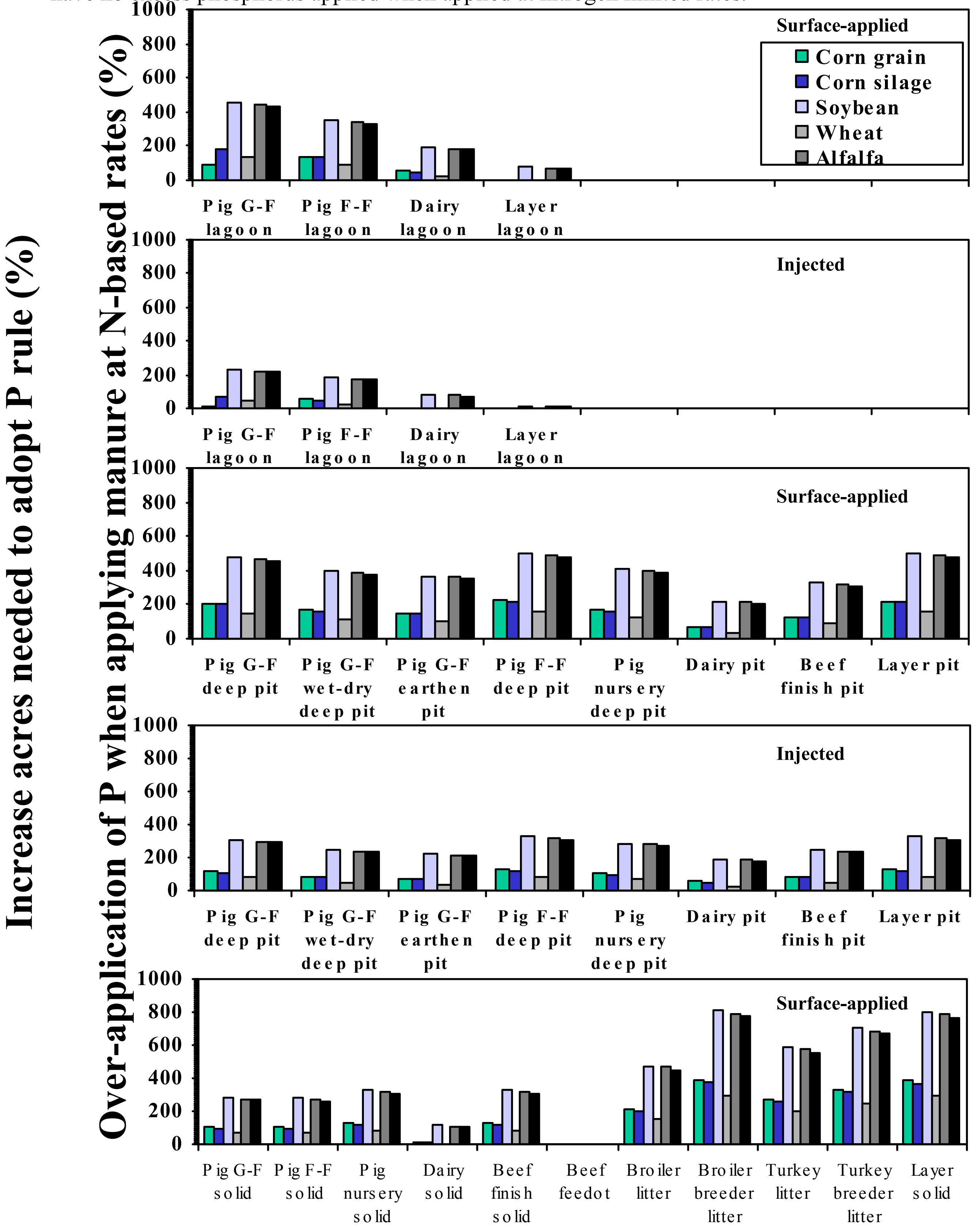

Figure 2-2. The effect of yield goal on the number of additional acres a farm requires to apply manure based on the phosphorus removal capacity of the crop. This example assumes the operation generates 18,000 lbs P_2O_5 per year as slurry from 1000 finish pigs and applies manure to corn grain crops.