Manure Application Rules and Environmental Considerations

Raymond E. Massey and Haluk Gedikoglu
University of Missouri and Lincoln University

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Abstract:

Three manure application limits (N Limit, Annual P Limit and P Banking) were modeled with particular attention to the number of hours needed to appropriately distribute manure. The benefit and costs estimates indicated that P Banking was more profitable than N Limit which was more profitable than Annual P Limit. The number of hours required indicated that the Annual P Limit would not be completed within a two month window approximately 2 of 10 years. The increased number of hours for the Annual P Limit also increased the probability of a runoff event following manure application, relative to the other two scenarios. This work indicates that regulations that require Annual P Limits of manure cost the farmer and may have the unintended consequence of increasing runoff.

Key words: runoff, hours, acres, probability, rainfall

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> "Too often it [manure] is regarded as a waste material to be disposed of in the easiest way possible. Frequently … on many farms' fields at some distances from the barns and feed yards are sometimes not manured at all (Stevenson, Brown et al. 1926)."

An interesting observation of this quote on manure management is that it was written in 1926 before the advent of modern fertilizers and therefore manure was the primary source of fertilizer. Manure management has always been difficult for farmers.

Many papers have written about the economics of manure management for individual farm profitability and environmental quality. Two characteristics of manure tend to be the focus of its odd place as a source of nutrients. First, manure has a low value:mass ratio. Commodities possessing a low value:mass ratio limit the distance the manure can be economically transported, resulting in localized markets (Keplinger and Hauck).

Second, the nitrogen:phosphorus ratio of provided my manure does not match the nitrogen:phosphorus ratio needed by crops. Farmers must choose a nutrient to use to determine their application rate. Choosing nitrogen (N) means phosphorus (P) is over-applied; choosing P means that N is under-applied.

Both N and P have environmental consequences, and thus are the target of environmental regulation. Nitrogen may leach into groundwater or be transported to coastal waters, causing eutropification(Vitousek, Aber et al.). Phosphorus can cause eutrophication of fresh waters (Sharpley, Daniel et al.).

Manure regulations historically have limited manure to the N needs of the crop receiving the manure but more recently have proposed limiting manure to the P needs of the crop. The use of a P index has been encouraged by NRCS standards. Phosphorus based applications are expected to reduce P runoff by ensuring that all P applied is removed at crop harvest. P based applications are considered best management practices because they almost always reduce runoff on a per acre basis. Pollution, however, is the result of all acres under production. Mandating practices like phosphorus based applications could change the number of acres under crop production, leading to more pollution (Norwood and Chvosta).

Norwood and Chvosta show that regulations designed to reduce P loading can result in unintended consequences such as increased nitrogen runoff. Unintended consequences occur when policy writers do not consider how managers will respond to regulations given their resources, constraints and incentives. (Norwood and Chvosta). This paper seeks to further understand the constraints and incentives that farmers face when making manure management decisions. Specifically, we elaborate on the time constraints and incentives. Time has impact on both the profitability of decision makers and the environmental impact of decisions made.

Farmers are assumed to apply manure where marginal cost equals marginal revenue. When economic studies indicate that farmers over-apply manure, they are 1) revealing a lost economic opportunity of farmers or 2) improperly specifying the marginal cost and return that farmers face. This study attempts to more properly specify costs by adequately accounting for time value and risk.

Sharpley et al. report that "in some agricultural watersheds, 90 percent of annual algal-available P export from watersheds comes from only 10 percent of the land area during a few relatively large storms (Sharpley, Daniel et al.)." Could P based applications, increase the amount of P in watersheds rather than reduce it? That is the question to which this paper hopes to provide insight.

Our objective is to optimize manure application in a multiple objective framework. Objective 1 is to maximize net income (minimize loss) associated with manure use as a crop fertilizer. Objective 2 is to minimize the probability of manure leaving the field and polluting water. The scenarios modeled will be ranked into efficient sets.

We will model land application of manure, concentrating on the number of acres and number of hours that different regulatory policies would require of manure managers. The default scenario will be a nitrogen limit (*N Limit*) where manure can be applied to meet the N needs of the crop. Two P based applications will be compared to the N Limit. The EPA proposed *Annual P Limits*, our first P based limit, in their revisions to manure regulations (U.S.

Environmental Protection Agency). The Annual P Limit has been modified by some to permit *P Banking*, our second P based limit.

An N Limit allows for the buildup of P in the soils and increases the chance of P pollution from the soils that receive manure. An Annual P Limit reduces the amount of manure applied to any one acre so all P is used by crop each year but insufficient N is applied. Annual P Limits do not reduce the amount of P applied each year. Rather they apply the same amount of P from the manure storage structure on more acres, each receiving a reduced rate. Additional N would need to be added to meet the crop needs.

P Banking limits application of manure supplied P to what can be removed by crops before a subsequent manure application can be applied. It allows application to meet the N needed by the crop in the year of application. The total number of acres needed over the planning horizon for the P Banking application can be identical to that of the Annual P Limit application. The number of acres accessed in any one year is the same as those accessed under the N Limit.

The impact of manure regulations on required acreage has been well documented (Fleming 1998; Norwood and Chvosta 2005). What has not been as explicitly studied is the impact of more acres on time required. Time is implied in the fact that accessing more acres will require greater travel distances. But this is handled in custom rates charging a base rate and a distance rate rather than specifically looking at the increased hours responsible for this increased charge. Fleming et al. acknowledge that costs might increase with tighter time constraints but do not consider them.

Application time in the field is a factor that needs to be added to the typical consideration of road travel time. Applying manure to more acres will increase the amount of application time in the field. The Annual P Limit requires access to more fields each year but each field receives less manure each year than the P Bank. Application time in the field will increase if the farmer is forced to cover 4 times as many acres as before. While lower application rates might allow for quicker application per acre, the total time will likely increase.

Model

Manure application options

We model three different manure regulatory scenarios (R) that have been considered. The default manure application rule is a nitrogen based application. Manure application is limited to the nitrogen needs of the subsequent crop (R = N limit). We also model to phosphorus based applications that have been considered in regulations. The annual phosphorus rule limits application of manure to the phosphorus removal of the subsequent crop (R = Annual P Limit). The P limit is relaxed to permit the application of manure to meet the N limit of the crop but not permit subsequent application until the P has been removed by crops (R = P Banking).

For purposes of illustration, we assume that manure is applied to fields cropped in a corn/soybean rotation. Manure is applied to corn fields because it increases the benefit of manure by valuing plant available N. Soybean fields do not receive manure but are used to take up excess P applied in the P Banking scenario.

Of particular importance to the 3 different strategies is the amount of land needed to properly use the manure. The nutrients supplied by manure in pounds per 1000 gallons (Nu_M) are applied so as to meet the nutrient needs of corn (Nu_C, pounds per acre). Under the N limit and P banking scenarios i = N; for the annual P limit, i = P).

(1) $$Nu_{M,i} = Nu_{C,i} \text{ for } i = N \text{ or } P$$

The application rate in 1000 gallons per acre is derived directly from the application rule (eq. 1)

(2) $$R_R = \frac{Nu_{C,i}}{Nu_{M,i}} \text{ for } i = N \text{ or } P$$

Required acreage for each regulatory scenario (RA_R) is equal to the quantity of manure (Q) divided by the application rate.

(3) $$RA_R = \frac{Q}{R_R}$$

Applying manure to meet the crop N needs in a single year results in the application of P in excess of what the crop will remove in a single year. This results in the buildup of soil test levels of P over time, creating an environmental risk.

The difference in the amount of land required for the N limit and either P limit depend on the manure and harvested crop characteristics (Norwood and Chvosta). Lory, et al. showed that the percent increase in acres needed if adopting a phosphorus rule (Δ) is a function of the N:P_2O_5 ratio of both the crop fertilizer need and the manure where:

(4) $$\Delta = \left(\frac{\text{crop fertilizer N} : P_2O_5 \text{ ratio}}{\text{manure N} : P_2O_5 \text{ ratio}} - 1 \right) \text{x } 100\%$$

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.

An Annual P Limit prevents the buildup of P in the soil. Nitrogen is under-applied under this rule so that, in addition to the manure, supplemental commercial fertilizer is applied to each corn field receiving manure.

Using a P Banking rule, manure is applied to meet the N needs of the crop and no more is applied until the phosphorus applied has been removed by the crops. Equation 4 gives the percent increase in acres needed to move from an N rule to a P rule. The number of years between manure applications would be $\Delta/100$ rounded to the nearest whole integer to account for whole years.

Following Fleming et al., not all acres near the manure source will receive manure. Search acres (SA_R) is a function of cropland in the vicinity (α), the percentage of cropland that is suited for receiving manure (β) and the percentage of suitable land that is actually available for receiving manure (γ).

$$(5) \qquad SA_R = \frac{RA_R}{\alpha\beta\gamma}$$

For simplicity, each field was assumed to be 100 acres and distributed around the manure source in a grid fashion (Fleming). Field size will impact field travel time discussed later in this section. Distance traveled to the required fields is a function of acres appropriate for manure application.

Delivery Cost

We first estimate the time required for manure transport and application. This time is multiplied by a custom rate in terms of dollars/hour to arrive at a total cost of manure transportation and application.

Manure application costs are calculated as a function of the time required to apply the manure under each regulatory scenario. Previous studies have recognized the importance of application rate on application cost. Keplinger and Hauck note that multiple year applications are necessary because annual application rates may not be attainable with current application equipment. Fleming et al. acknowledge the importance of time constraints on manure management decisions but admittedly do not account for increasing costs associated with tighter time constraints.

Total time required to apply manure under each of the regulatory scenarios (TT_R) is the sum of the time road travel time from the manure source to the fields receiving the manure (RT_R), the field travel time to get to the point in the field where application begins (FT_R) and the actual application time when manure is applied to the fields (AT_R).

(6) $$TT_R = RT_R + FT_R + AT_R$$

Road travel time (RT_R) is a function of the median distance traveled to all fields (D_R) in miles, the road speed (S_T) in miles per gallon, the rate of application (R_R) in gallons per acre, the capacity of the manure spreader (C), the total number of acres receiving manure (A_R). This time is multiplied by 2 to account for a round trip.

(7) $$RT_R = \frac{D_R}{S_T} x \frac{R_R}{C} x A_R x 2$$

D_R is the sum of the minimum distance (assumed 0 miles) and the maximum distance divided by two. Maximum one way mileage is 2 times the square root of SA divided by 640 acres in a square mile.

Field travel time (FT_R) accounts for the inefficiency of repeatedly returning to wherever in the field the last load of manure was delivered. It results from supplying crop nutrients with low nutrient bulk product. The equation for this is in the appendix as it is a function of field dimensions and not any decision that the manager makes.

Field Application time (AT_R) is a function of the number of acres required for each limit (RA_R), the speed of the application equipment (S_R) in miles per hour and the swath width of the application equipment (W_R) in feet. As indicated by Keplinger, current application equipment limits may not permit extremely low application rates at normal travel speeds and swath widths. Using equipment that pierces the soil as it splashes manure using a 15 foot tool bar (e.g. Aerway), the acceptable range of field travel speed is 1 to 5 miles per hour. The discharge rate is constrained to be between 300 and 1000 gallons/minute. Under low application rates (e.g. Annual P Limit), the speed will be increased until it reaches the maximum. The actual application time is multiplied by 2 to model the time necessary for the equipment to return to where it began applying manure.

(8) $$AT_R = \frac{RA_R}{S_R \, x W_R} x \frac{1 mile}{5280\,ft} x \frac{43560\,ft^2}{Acre} x 2$$

Delivery cost is a simple function of the number of hours required to distribute the manure multiplied times a custom rate (*r* in dollars per hour).

(9) $$DC_R = TT_R r$$

Benefit

The benefits to manure application include: 1) the value of the crop nutrients supplied by the manure and 2) the reduced commercial fertilizer application costs, if avoided.

The value of only the N and P are considered in this analysis since they are the nutrients under consideration for regulation. Potassium is a crop nutrient supplied by manure in a quantity that meets crop needs under all regulatory scenarios. For the N limit and Annual P Limit, nutrients have value only in the year they are applied; for the P Banking limit, all P applied has value since it is used by the crops before another application of manure is permitted.

The total benefit from manure for each of the regulatory scenarios (TB_R) is:

(10) $$TB_R = \sum_{A=1}^{RA_R} \sum_{i=N,P} p_i Nu_{M,i,R} + F_R A_R$$

$$Nu_{M,i} \leq \frac{Nu_{M,T}}{Nu_{C,T}} Nu_{C,i} = \frac{Nu_{C,i}}{R_R} \; for T = N \; or \; P \; and \; i = N \; or \; P$$

where p_i is the commercial price for fertilizer nutrient (\$/pound); A is the number of acres; and F is the cost of commercial fertilizer application:

$$(11) \quad F_R = \sum_{A=1}^{RA_R} AppFee_A \; if \; Nu_{M,i} \geq Nu_{C,i} \; forall\, i, i = N \; and \; P$$
$$= 0 \; otherwise$$

where AppFee is the fixed application fee ($/acre) for applying commercial fertilizers.

Net benefit to the farmer is simply the TB less the DC.

Probability of manure leaving the field

The objective of manure regulations that limit the amount of manure that can be applied to a single field is to reduce the quantity of manure that enters water bodies. The thought behind an annual P application is that it reduces the amount of manure applied to each field so less is likely to runoff from that field. This reasoning overlooks the fact that all the manure produced by a livestock facility has to eventually be applied to fields. Light applications are applied to many fields; heavy applications to fewer fields.

The amount of manure that enters water is dependent on the amount of manure on a particular field and the probability that a particular field will experience a runoff causing precipitation event.

Manure runoff occurs when rainfall of a sufficient quantity occurs before manure which has been applied to a field has time to be incorporated into the soil. The probability of a runoff event increases with 1) soil type and slope and 2) proximity of manure application to a runoff causing rainfall event. The regulatory rules of manure application affect both of the factors affecting the probability of a runoff event. Manure application rules that require lighter applications require more land be found and more time.

As more land is required, the amount of land suitable to receiving manure decreases. Environmentally sensitive land (e.g. greater slope or closer to water bodies) that may have been avoided under an N Limit rule might be used under an Annual P Limit rule because of the difficulty in finding suitable land. Land that may have utilized the N (e.g. corn ground) may be not be used in order to get land closer to the manure source (e.g. growing soybeans or alfalfa).

Increasing the number of hours required increases the probability of a runoff event in the following ways: 1) the time when manure can be applied and incorporated into the soil prior to a runoff event diminishes; 2) farmers are more likely to apply prior to a forecasted runoff event simply because the additional time needed for application affords little choice; 3) farmers are likely to work more hours in a day to complete the activity increasing the likelihood of working in the dark and having an accident.

We estimate the probability of a runoff event in two steps. First, we estimate the probability of finishing manure application during a specified period. We used the October – November period to illustrate manure application following harvest. A spreadsheet program developed at the University of Missouri (Carpenter and Massey) estimated the probability of completing the manure application using fieldwork day data (USDA) and assuming that application occurred during daylight hours.

The probability of finishing within the appropriate fieldwork days decreases as the number of hours required increases. As the probability decreases, managers will make decisions that favor their management objective (i.e. get the manure out on the nearest acres).

Next we estimate the probability of a rainfall event expected to cause a runoff event occurring within 24 hours of manure application. For illustration, we use a permit rule currently in use in Michigan that prohibits application within 24 hours of a ½ rainfall forecast event. The probability of a runoff causing event within 24 hours of application will increase as the number of hours required increases.

A Markov chain model is used to determine the probability of a .5 inch rainfall occurring within 1 day of a dry day suitable for manure application (Gabriel and Neumann 1962). It is recognized that the amount of rainfall needed to create a runoff event is dependent on many factors. We chose .5 inches as a proxy that can be expanded in later work to more accurately model runoff events.

Decision rule

The results will be evaluated under a traditional risk-return framework. More net benefit is preferred to less; less risk of manure leaving the field is preferred to more. A policy scenario is preferred to another if simultaneously its net benefit to the farmer is greater than another scenario and its risk of manure leaving the field is less than that same scenario.

Application/Example

The following example is to illustrate the methodology employed. It is preliminary (at the time of this presentation at the 2011 SAEA) and is being refined. Please do not take the example as definitive. Results of the example are reported in table 1.

We assumed a farrow-to-finish hog operation using pit manure. Each year 1.1 million gallons of manure is produced and applied to cropland. The manure provides 15 lbs N and 18 lbs P_2O_5 per 1,000 gallons. Corn production at 150 bu/ac is assumed to need (or remove) 165 lbs N and 45 lbs P_2O_5 per harvest. Soybean production at 50 bu/ac is assumed to remove 100 N and 30 lbs P_2O_5 per harvest.

For purposes of illustration, we used a P banking period of 4 years. This was arrived at by assuming manure was applied to corn with a N: P_2O_5 ratio of 3.3 and farrow-to-finish pit manure with a N: P_2O_5 ratio of .83. Using equation 4, this gives a Δ of 3.96, which was rounded up to 4.

Figure 1 summarizes our field setup for all regulatory scenarios. It is broken into 4 fields on the assumption that one field represents 1 year and we need to show the effects of a 4-year P Banking period. Under the N limit, fields 1 and receive manure in the years that corn is grown on those fields in a corn-soybean rotation (year 1 for field 1; year 2 for field 2). Since Δ is 4 in our example, neither field 1 nor field 2 will use all the phosphorus before another application of manure is applied in years 3 and 4. This reapplication of manure before the previous P is removed by the crop means that the supply of P exceeds the demand for P and the fertilizer value of P in the N limit scenario is set at $0.

For the Annual P Limit, each field receives manure each year to meet the P needs of the crop. The same amount of manure is being applied as in the N Limit scenario, so the application rate is ¼ of the N Limit rate. Supplemental, commercial N fertilizer is applied to the two fields each year that are planted to corn to meet the N needs of the corn.

For the P Banking scenario, each year a different field receives manure. It is applied to meet the N needs of the corn crop grown following the application of manure. Manure cannot be reapplied on field 1 until all the manure supplied P has been removed by the crop. This causes the manure to go to field 2 in year 2; field 3 in year 3; and field 4 in year 4. Since all of the P on field 1 has been removed by crops in year 4, manure can be reapplied to field 1 in year 5. The P Banking scenario uses twice as many fields over the course of the 4-year planning horizon than does the N Limit scenario even though the application rate in each year is the same as the N Limit scenario. Because all of the P applied is used by the crops before it is reapplied, all P applied is valued at its commercial value.

The application rate for manure is 11,000 gal/ac for the Nitrogen Limit and the P Bank scenarios. It is 2,500 gal/ac, or ¼ that amount, for the Annual P Limit. The acres needed each year are 100 for both the N Limit and P Bank scenarios; 400 for the Annual P Limit. Assuming α, β and γ to each be .5, the number of search acres becomes 800, 3,200 and 1,600 for each of the scenarios, respectively. The larger search areas result in longer travel distances and road travel time. The Annual P Limit Road Travel Time is twice that of the N Limit; the P Bank is 1/3 greater than the N Limit. The annual Field Time is the same for the N Limit and P Bank scenarios at 69.4 hours; it rises to 102.2 hours for the Annual P Limit.

Assuming a custom application charge of $125/hour, the distribution cost is $13,799 for the N Limit, $23,021 for the Annual P Limit and $15,921 for the P Bank scenario. Using fertilizer prices of $.4/lb N, $.5/lb P2O5 and $.6/lb K2O, and custom fertilizer charges of $8/acre, the total benefit of meeting crop nutrient needs by manure is $9,875 for the N Limit, $18,100 for the Annual P Limit and $18,100 for the P Bank scenario. The net economic benefit of manure use is -$3,924 for the N Limit, -$4,921 for the Annual P Limit and +$2,178 for the P Bank scenario.

The PDFM software estimated that the probability of inability to comple of manure application activities within the October-November window to be 0% for both the N Limit and P Bank scenarios and 21% for the Annual P Limit Scenario. Zero percent probability for N Limit and P Bank probably underestimates the risk of manure application but the difference between them and the Annual P Limit illustrates the increased risk of an Annual P Limit regulation.

Using 30 year historical rainfall for Columbia, MO, the probability of a rainfall event following the application of manure was estimated at 5.8% for the N Limit and P Bank scenarios; 6.1% for the Annual P Limit scenario. Again, the accuracy of probabilities are preliminary. But the sign indicates that there is a greater probability of a runoff event for the Annual P Limit than for the other 2 application scenarios.

The efficient set (highest net benefit, lowest probability of runoff) is the P Bank, followed by the N Limit, followed by the Annual P Limit as illustrated in Figure 2. The P Bank scenario was preferred to the N Limit because it had the highest net benefit and the same probability of runoff. Theoretically, though not empirically in this example, the P Bank should have had greater probability of runoff than the N Limit because it required more hours to perform. The N Limit is preferred to the Annual P Limit because it has a greater net benefit (smaller net loss) and a smaller probability of experiencing a runoff event.

Discussion

The research illustrated the importance of hours of fieldwork on choosing a manure application rate limit. It built upon previous research to begin establishing a value for the marginal hour of application time. While the P Bank was preferred to the N Limit, many farmers continue to apply based on N needs of the crop, and thereby wasting the P value of the manure. This could be explained by the additional hours needed to apply the manure in a P Bank manner. The Annual P Limit, though the total benefit of the manure was greater than the total benefit under the N Limit, could not overcome the cost of the increased hours of application. Our analysis probably underestimates the actual cost of an Annual P Limit because we did not increase the cost of additional hours even though the results indicated that 2 out of 10 years the work would not be completed on time. Additional equipment would be necessary to complete the work in those years.

In addition to recognizing the impact of needed hours to the producer, this research illustrated the impact of additional hours to environmental quality. The additional hours needed for an Annual P Limit would likely increase the probability of runoff events. The quantity of manure reaching water under each scenario is still uncertain. While the Annual P Limit would have a greater probability of runoff following application, the quantity applied in the preceding day would be lower than for the N Limit and P Banking scenario. However, it must be understood that the total quantity of manure applied to fields is the same for all scenarios. Limiting application rate does not diminish the amount of manure applied. It changes where it is applied and the time it takes to apply it. This research indicates affirms Norwood and Chvosta research that indicated imposing a P limit on manure applications could have the unintended consequence of increasing manure runoff and decreasing environmental quality.

The quantity of manure to be applied would play a large role in results. Smaller livestock operations might be able to complete their manure application activities within the acceptable window with little probability of runoff, regardless of the application limit. But regulations target large livestock operations. Larger livestock operations would require more hours to apply manure and either have to invest additional money in application equipment or increase the probability of a runoff event following manure application.

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Figure 1. Illustration of Manure Application Limits by Field and Year.

Field 1	Field 2
N limit: manured in year 1 & 3	N limit: manured in year 2 & 4
Annual P limit: manured in years 1,2,3 & 4	Annual P limit: manured in years 1,2,3 & 4
P banking: manured in year 1	P banking: manured in year 2
Field 3	**Field 4**
N limit: not manured	N limit: not manured
Annual P limit: manured in years 1,2,3 & 4	Annual P limit: manured in years 1,2,3 & 4
P banking: manured in year 3	P banking: manured in year 4

Figure 2. Illustration of Efficient Set

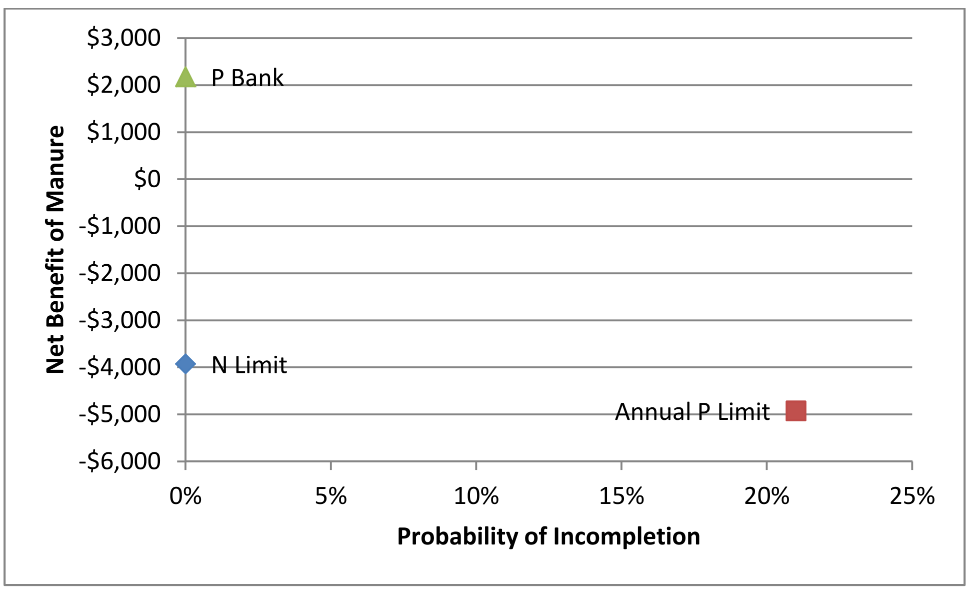

Table 1. Results of the illustration

	Regulatory Scenario		
	Nitrogen Limit	Annual P Limit	P bank
Application Rate (gal/ac) (R)	11,000	2,750	11,000
Acres needed/year (RA)	100	400	100
Search Acreage (SA)	800	3,200	1,600
Median Distance Travelled (D)	1.1	2.2	1.6
Road Travel Time (RT)	41	82	56
Field Time (FT + AT)	69.4	102.2	69.4
Total Time (TT)	101.4	184.2	127.4
Distribution Cost (DC)	13,799	23,021	15,921
Total Benefit	9,875	18,100	18,100
Net Benefit	-3,924	-4,921	2,178
Probability of completing within application window	100%	79%	100%
Probability of runoff event following application	.058	.061	.058