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Implications of alternative environmental policies on phosphorus loading from poultry litter

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Abstract

Degraded groundwater, impaired swimming, fishing, algae and weed problem are often associated with eutrophication from phosphorus (P) loadings in surface and groundwater. The concentrated growth of poultry industry and over application of litter on pasture lands may lead to excessive nutrient loadings in surface and groundwater. The Cooperative Extension Service recommendation suggests that no poultry litter should be applied if the soil test P exceeds 300 pounds per acre, irrespective of the marginal costs and benefits associated with one more unit of litter application on that piece of land. The objective of this paper is to model the economics of P loadings from poultry litter and analyze the policy implications of Cooperative Extension Service's recommendation on quantity restriction on litter applications with empirical evidence. The results indicate that there exists significant difference in the marginal values of soil between different soil series, indicating that the permit system can achieve the target at a lesser cost. In particular, the society as a whole can gain \$2.7 per acre by allocating the litter to soil series 16 instead of soil series 20, provided that the contribution towards groundwater contamination from these two acres are the same.

1. Introduction

Eutrophication from high levels of phosphorus (P) loadings can cause algae and weed problems in lakes (Larsen and Mercier, 1975). Degraded water palatability, impaired swimming, fishing and aesthetic enjoyment of a valuable lake resource are also often associated with eutrophication. The Environmental Protection Agency's National Eutrophication Survey has explicitly identified the potential eutrophication problems associated with P loadings. Agriculture is one of the contributors of non-point source pollution including P loadings in surface and groundwater from activities such as excessive fertilizer application and improper animal waste management (National Research Council, 1989). The size of the poultry industry in Arkansas has exploded during the past decade producing about 24 million chickens, 25 million turkeys and one billion broilers every

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year. As a result, approximately 1.5 million tons of poultry litter are produced per year. The concentrated growth of poultry industry and over application of litter on pasture lands may lead to excessive nutrient loadings in surface and groundwater.

Policy makers are searching for efficient ways to control nutrient loadings from poultry litter. Although, no explicit state environmental policy on phosphorus handling exists, the US Cooperative Extension Service recommends that any producer farming land that has elevated levels of P not apply poultry litter to improve crop production (Cooperative Extension Service, 1992). More specifically, recommendation suggests that no poultry litter should be applied if the soil test P concentrations exceed 300 pounds per acre, irrespective of the marginal costs and benefits associated with one more unit of litter application on that piece of land. Ideally, the policy instrument should take into account of a variety of soil characteristics such as productivity, erosion potential, porosity, salinity, assimilative capacity and other characteristics such as proximity to the surface and groundwater and the slope of the land. Thus, there may be some cost-benefit differentials between soil types in limiting the quantity of litter application.

Much less is known about the economics of controlling the litter application to curtail P and other loadings in surface and groundwater. The objective of this study is to model the economics of P loadings from poultry litter and analyze the policy implications of Cooperative Extension Service's recommendation on quantity restriction on litter applications. We also conduct an empirical analysis of the marginal value of different soil series with litter applications in the Muddy Fork watershed of the Illinois River in northwest Arkansas.

2. Theoretical model

The model section is sub-divided into three sections. First, we formulate a microeconomic model to capture the impact of the current environmental policy on phosphorus (P) loadings. A similar approach to achieve Pareto optimal solution was developed by Govindasamy and Huffman (1993) and Tietenberg (1985). Second, we analyze the implications of the current regulation and the rate of compliance under the uniform recommendation of maximum allowable soil test P loadings of 300 pounds per acre. Third, we develop an alternative solution to overcome the limitations associated with the uniform recommendation.

2.1. Microeconomic model of environmental regulation

Consider only those lands which would come under Phosphorus Management Policy (PMP). The current objective of the regulation is to restrict the soil test P concentration to 300 pounds per acre or below.

Symbolically, the relationship between the target P loadings and the actual P loadings can be represented as

$$C \geq a \tag{1}$$

where a represents the actual P concentration in an acre of soil, and C denotes the maximum allowable soil test P concentration in an acre of soil, i.e., 300 pounds per acre. Assume that there is one-to-one relation between the P concentration in the soil and the application of litter which can be represented as

$$a = f(x) \tag{2}$$

where $f(x)$ represents the transformation function from litter application to P concentration in the soil with x being the amount of litter applied per acre. The loss of P in runoff is directly influenced by the P content of surface soil. Sharpley et al. (1986) observed a highly significant linear relationship between the soil test P content of surface soil and the dissolved P concentration in runoff from cropped and grassed watersheds in Oklahoma. By the nature of the transformation function, the P concentration in the soil is assumed to increase with the amount of litter application, that is $f'(x) > 0$. Let

$$\pi(a,b) \tag{3}$$

be a continuous profit function which depends on the actual P concentration a, and other composite inputs b. It should be noted that although the soil test P does not influence the yield beyond a critical value, the other components of the poultry litter such as nitrogen, potassium and microbial activities may affect the yield. By substituting Eq. (2) in Eq. (3), we get

$$\pi[f(x),b] \tag{4}$$

The profit function is assumed to have the following two properties.
1. The poultry litter has a positive influence on profit but at a decreasing rate and,
2. The change in profit due to a unit change in the poultry litter application depends on the level of poultry litter application.

First, consider the increase in the profit due to increase in the poultry litter application. It implies that

$$(\partial\pi/\partial x) > 0$$

That is, the value of marginal product of litter (VMP) is positive. This concept can be explained using positive marginal productivity. At low levels of litter application the value of marginal product will be high compared with the high levels of litter application. Since the current policy requires that no litter can be applied to any land where the soil test P concentration exceeds 300 pounds per acre, the initial application will greatly contribute towards profit.

Second, consider the rate of change in profit due to a unit increase in litter application. This relates to the diminishing marginal productivity assumption because the marginal physical product is a function of the level of the input. Given diminishing marginal product and a constant price, the profit will increase at a decreasing rate as the litter input increases.

The objective is to maximize social welfare from every acre of land which can be represented as

$$\operatorname{Max} L = \pi[f(x),b] - \mu_i[f(x) - C] \tag{5}$$

In Eq. (5) social welfare is maximized by maximizing the returns from production, with the application of litter, subject to the constraint that the P concentration in the soil should not exceed C. The opportunity cost of applying one more unit of poultry litter for the ith acre of land is represented by μ_i. The opportunity cost of litter also takes into account of the cost of transportation of litter to production regions where the value of marginal product of litter is higher. Although in some instances, the cost of transporting litter could be prohibitive, if the value of marginal product of litter is sufficiently high, then it is feasible to transport the litter (Govindasamy and Cochran, 1995). The familiar first-order conditions for maximization imply that

$$x:(\partial L/\partial x) = \pi'[f(x),b]f'(x) - \mu_i f'(x) \leq 0 \tag{6}$$

$$b:(\partial L/\partial b) = \pi'[f(x),b] \leq 0 \tag{7}$$

$$\mu_i:(\partial L/\partial \mu_i) = f(x) - C \leq 0 \tag{8}$$

In the context of poultry litter application, the composite input b can be considered as nitrogen, potassium, pesticides and labor. The complementary slackness conditions imply that

$$x\pi'[f(x),b]f'(x) - \mu_i f'(x) = 0 \tag{9}$$

$$b\pi'[f(x),b] = 0 \tag{10}$$

$$\mu_i f(x) - C = 0 \tag{11}$$

$$x,b,\mu_i \geq 0$$

Assuming interior solutions, Eq. (6) can be simplified as

$$\pi'[f(x),b] = \mu_i \tag{12}$$

Eq. (12) implies that there exists an x^* such that the marginal benefit from the application of litter should equal the marginal opportunity cost of the litter on the ith acre of land. Here, x^* indicates the optimal rate of litter application on each acre of land. We do not consider the acquisition cost and the spreading cost of the litter. If $\mu_i = 0$, it implies that

$$f(x) < C \tag{13}$$

That is the P concentration in the soil is less than the maximum allowable target. Under such a situation, there is no need to control the application of poultry litter.

The x^* defined by Eq. (12) is Pareto-inferior, because the marginal benefit from litter application is equated to opportunity cost of litter application on the ith acre of land. There exists a Pareto-superior solution where the marginal benefit should be equated to the opportunity cost of not just the ith acre of land but on any acre of land.

2.2. Implications of current policy

The current policy have two major implications in terms of efficiency to control P loadings into the ground and surface water from land applications of poultry litter. First, consider the impact of establishing a uniform soil test P concentration of 300 pounds per acre. The loadings of P depends on the various characteristics of the soil such as the hydrous oxides of iron and aluminum, alumino–silicate minerals, soil carbonates, organic matter and other factors such as the erodability potential, crop cover, tillage practices, rainfall intensity, and the proximity to a surface water source sensitive to eutrophication (Sims and Wolf, 1993). The optimal application rate of the poultry litter is dictated by Eq. (12) where the marginal benefit generated by unit litter application equals the marginal damage caused by the same unit of poultry litter. Both the marginal benefit and the marginal damage cost of the unit litter varies according to the soil qualities as well as the location of the land.

Consider the marginal damage caused by a unit application of litter. The degree of damage depends on the soil characteristics, the slope and location of the land. Therefore, a restriction on the tons of litter that can be applied to a piece of land should be variable, depending on soil and other characteristics rather than a uniform rate. Now consider the marginal benefit associated with unit application of litter. The benefits from the unit application of litter is a function of soil characteristics, yield responses and crop prices. Experimental results (Rainey et al., 1992 and Miller et al., 1991) show that poultry litter has a higher impact on "problem" soils compared with other soils. The "problem" soils refer to soils that have been put to grade, alkalized soils and chloride-affected soils. If everything else is constant, soils that have a higher value of marginal product should receive more litter compared to other soils. Therefore, imposing a uniform restriction on litter applications to soils which test higher than 300 pounds per acre phosphorus would induce a non-Pareto optimal allocation. It should be noted that the introduction of restrictions based on each soil type may increase the administrative costs such as information costs, control costs, and enforcement costs.

Second, consider the impact of establishing a uniform P concentration on a piece of land. Consider one acre of land A with a high value of marginal product and another acre of land B with low value of marginal product. If both the pieces of land transport P to the same surface water which is sensitive to eutrophication, then the land with the low value of marginal product must be assigned with a higher control of litter application compared to the land with high value of marginal product. Therefore, to achieve Pareto optimal allocation of resources, we need to consider not only the marginal benefits and marginal cost associated with unit application of litter for a particular soil but also the benefits and costs associated with different soils.

2.3. Achieving the efficient solution

Consider a watershed where the runoff of P leads to a single surface water source. There are two possible effects. First, the yield response to litter application will vary according to different soil types implying that the optimal rate of litter application is a function of soil types within the same watershed. Second, it is possible that the relationship between the litter application and P loadings could also vary depending on soil and land characteristics.

For simplicity, we consider the land where there exists some differences in yield response to litter, but have the same loading potential of P into the surface water. The objective of the policy is to control the rate of litter application on these soils. Given that the loading potential of the soils are the same and there exits some differences in the yield responses to litter application, the optimal litter application for the entire watershed can be determined using the P concentration in the surface water. Now given the optimal total litter application for the entire watershed, the question is how to determine the optimal litter rate for each acre in the watershed.

The efficient solution can be achieved by issuing marketable litter application permits for each acre of land based on the target P concentration. Assume that the optimal level of litter application for the entire watershed is given by C^* pounds. Then the total number of permits to be issued for the entire watershed is given by

$$C^* = N \tag{14}$$

where N represents the number of permits to be issued. Let K represent the total acres that come under the program. Then each acre will receive

$$a = N/K \tag{15}$$

number of permits, where a is the number of permits issued per acre such that

$$\Sigma \mathrm{i} = 1Ka = aK = N \tag{16}$$

When these permits are issued, they will have a positive price as long as some litter application control is required. The owner of the land will attempt to acquire or sell the number of permits that will maximize his or her returns. When these permits are issued, the maximization problem given in (5) can be modified as follows.

$$\mathrm{Max}\, L = \pi[f(x),b] - y[f(x) - An_{\mathrm{i}}] \tag{17}$$

where y is the price a source would pay for an acquired permit or receive for a permit sold to another source. The first-order conditions for the maximization problem is given by

$$x:(\partial L/\partial x) = \pi'[f(x),b]f'(x) - yf'(x) \leq 0 \tag{18}$$

$$b:(\partial L/\partial b) = \pi'[f(x),b] \leq 0 \tag{19}$$

$$y:(\partial L/\partial y) = f(x) - An_{\mathrm{i}} \leq 0 \tag{20}$$

The complementary slackness conditions are given by

$$x\pi'[f(x),b]f'(x) - yf'(x) = 0 \tag{21}$$

$$b\pi'[f(x),b] = 0 \tag{22}$$

$$yf(x) - An_{\mathrm{i}} = 0 \tag{23}$$

$$x,b,y \geq 0$$

Assuming interior solution Eq. (21) can be simplified as

$$\pi'[f(x),b] = y \tag{24}$$

Eq. (24) implies that there exists an x^{**} such that the marginal benefit from each acre of land from litter application equals the opportunity cost of litter application on any acre of land. The variable y can be thought of as the opportunity cost of applying one more pound of litter to an acre of land.

The solution x^{**} defined by Eq. (24) is Pareto-superior to the solution x^* defined by Eq. (12) for the following reason. Consider two acres of land i and j, where the ith acre of land is more responsive to litter application than the jth acre of land. According to Eq. (12), the solution x^* would equate the marginal benefit from the ith (jth) acre of land to the opportunity cost of litter application on the ith (jth) acre of land, given the constraint that the P loadings cannot exceed a certain limit on each acre of land. The constraint on P concentration on each acre of land in turn implies that there is a limit on the number of pounds of litter that can be applied to each acre of land. Given the total pounds of litter that can be applied to the two acres of land i and j, ideally, the ith acre of land should be able to receive a higher rate of litter compared with the jth acre because the marginal benefit of litter application is higher in ith acre than the jth acre. This is accomplished by Eq. (24), where the ith producer can buy a permit from the jth producer so that he or she can apply one more pound of litter to the soil. The marketable permit system allows for increased total product and hence the total revenue in spite of the fact that the total litter application in the watershed remains the same.

In general, marketable permit system is appealing from the efficiency point of view because it possesses the least-cost property (Baumol and Oats, 1988). The marketable permit system basically defines property rights for environmental resources and then offered for sale to the highest bidder (Dales, 1968). The permit system has some advantages over effluent fee for the attainment of a set of predetermined environmental standards.

First, permit system reduces the uncertainty and adjustment costs in attaining legally required levels of environmental quality. Second, by using the permit system, one can avoid the complications that result from economic growth and price inflation in using the fee system. Third, at the time of introduction of the scheme, permit system can be smoothly introduced by issuing free permits whereas the fee system will pose a threat to the existing firms. Fourth, permits already exist and therefore it may be a less-radical step for introduction than a fee system.

Some limitations do exist for practical implementation of marketable permit system. First, it might be cumbersome to establish the carrying capacity of the watershed in terms of C^* pounds of litter that can be applied. Also, C^* is time dependent, which means that the carrying capacity must be evaluated periodically. Second, from an administrative point of view, it is costly to collect information and enforce the policies for each acre. Third, the P content of the manure is dependent on the composition of feed and efficiency of feed conversion. The means and variances of P content in the manure must also be considered. Fourth, the transaction costs of creating a functional market for the permits should be assessed prior to implementation. We also note that there is an upper bound on the transaction cost associated with the permit for the system to be efficient. Fifth, it might be difficult to control over application of poultry litter on environmentally sensitive lands, especially when that land has a high value of marginal product of litter. Since the permits are tradable, only those producers with high value of marginal product of litter can afford to buy the permits at high price. Sixth, the implementation of policy that controls P application also impacts other nutrient loadings such as nitrogen into surface and groundwater. Also, to realistically regulate the phosphorus loadings, other sources such as livestock manure and chemical fertilizers must also be incorporated into the model. Finally, the political justification of giving equal number of permits to each acre and its impact on the redistribution of wealth must be examined before implementation.

3. A graphical illustration of the efficient solution

Consider Fig. 1. The y axis represents the value of marginal product for acre i and acre j for

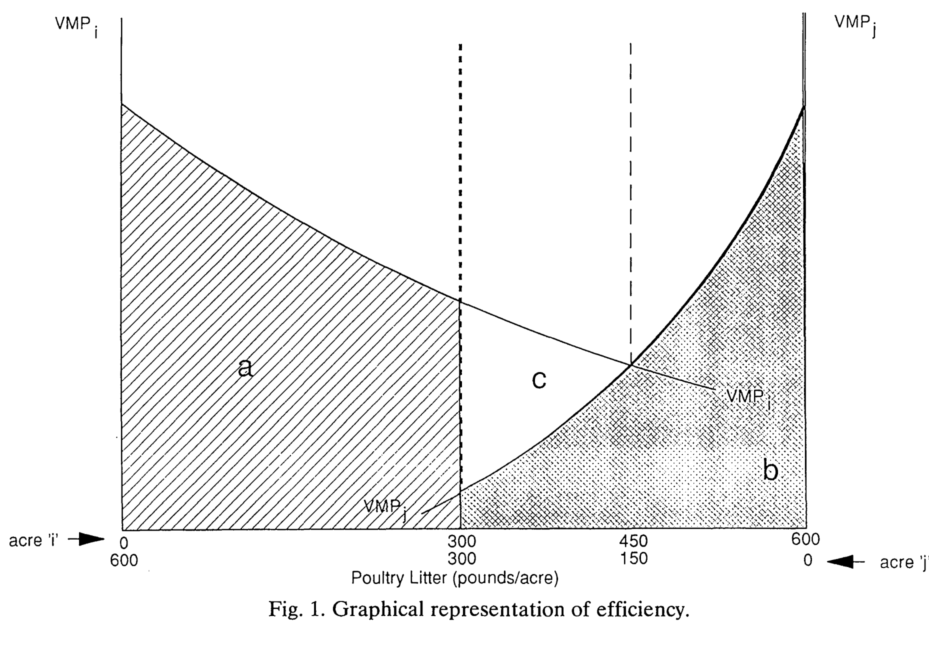

Fig. 1. Graphical representation of efficiency.

the application of poultry litter. The x axis represents the quantity of litter applied in pounds acre. The gently downward sloping curve indicates the value of marginal product curve for litter on the ith acre and the steeply downward sloping curve indicates the value of marginal product of litter on the jth acre. If each of the ith and jth acres are restricted to apply soil test P of 300 pound per acre, the total value product (TVP) for the two acres is given by area

$$TVP_{300\text{ pounds}/\text{acre}} = a + b \tag{25}$$

in Fig. 1. Now, analyze the TVP for the permit system which allows for the buying and selling of tradable permits. The producer who owns the land where litter has a high value of marginal product, (i.e., the ith acre) can buy permits to apply 150 pounds more of poultry litter on the ith acre in addition to 300 pounds. As a result the total litter applied in the watershed remains the same, whereas the total value product is given by the area

$$TVP_{\text{tradable permit}} = a + b + c \tag{26}$$

For the society as a whole, the total value product increases by

$$TVP_{300\text{pounds}/\text{acre}} - TVP_{\text{tradablepermit}} = c \tag{27}$$

The transaction cost associated with the tradable permits can be represented as TC, so that the net benefit to the society as a whole can be depicted as

$$c - TC = NB \tag{28}$$

where NB represents the total net benefits associated with tradable permits after the transaction costs. This proves that the solution to Eq. (12) x^* is Pareto-inferior to solution to Eq. (24), i.e., x^{**}.

The simulations of phosphorus restrictions and the rate restrictions for the entire watershed indicate that the current recommendation on phosphorus loadings will significantly reduce the profits from forage production. With introduction of permits or any other environmental regulation that takes account of the marginal value of litter on different soil series, the loss of profit for the entire watershed can be greatly reduced. On average, ignoring the variability of environmental impacts, the gains to society due to the introduction of an environmental regulation that takes into account of the marginal value of different soil series is directly proportional to the prices of crops. With P restriction, some portion of the soils that are significantly responsive to litter may be eliminated from crop production. As a result, it is possible that not only the objective function value may go down, but also the remaining acres may receive more litter on a per acre basis. This process may aggravate the rate of phosphorus accumulation process in the soil series where the soil test phosphorus is below the critical level and may exacerbate the nitrate loadings problem.

4. Empirical analysis

A programming model is formulated using General Algebraic Modeling System (GAMS) (Brooke et al., 1988). The objective function in this model maximizes profit from the Muddy Fork watershed of the Illinois river in Washington county, Arkansas. The primary objective of this empirical analysis is to show that there exists a wide range of marginal values for land depending on its response to litter application, rates of application of litter, fertility and other characteristics. As a result, the permit system can achieve the target level of litter applications at a lesser social cost compared to a quantity restriction. To formulate the mathematical programming model, specific soil units were aggregated into a manageable number of soil classes based on the physical characteristics determining yield responses. The soil resources data were provided by the Geographic Information System (GIS) of the Department of Agronomy at University of Arkansas, Fayetteville. The study area consists of nine major soil series: Captina(6), Enders(11), Hector–Mountainburg(16), Jay(17), Johnsburg(18), Linker(20), Pembroke(23), Savannah(28), and Summit(31). The other minor soil series were aggregated together for simplicity (represented as series 0).

The inputs to the programming model were derived using a GIS analysis and standard budgeting. The standard budgeting was carried out using field experimental data to analyze the profitability of bermudagrass and tall fescue on ten different soil series, with five different application rates (0, 1, 2, 3, and 4 tons/acre) and four different times of litter application [spring, summer, fall, fall/spring (implies application in both fall and spring)].

The mathematical programming model can be divided into seven sections (Buchberger, 1991). First, the objective function maximizes the net returns over variable costs from various activities consisting of tall fescue and bermudagrass net of excess poultry litter transportation costs or benefits and storage cost of the litter. In each scenario, based on a survey on litter use in northwest Arkansas (Rutherford, 1993), three poultry litter price subscenario were analyzed: sale price of litter \$7 ton^{-1}; sale price of litter \$5 ton^{-1}; and disposal cost of litter $\$-0.005$ ton^{-1}. A set of base prices on bermudagrass and tall fescue were used to analyze the impact of phosphorus loadings constraint on profitability for the entire watershed. Second, the soil class acre constraints place an upper bound on the number of acres available on each of the ten soil series covering approximately 47,000 acres, out of which 29,950 acres are currently in pasture in the Muddy Fork watershed. Third, the phosphorus management constraint limits the acres that are available for application after eliminating the excess P concentrated lands. This imposes additional restrictions on the soil class acre constraints. Fourth, the government cost-sharing in the projects is incorporated to analyze the impact on profit from the water quality special project. The program is a joint action of Soil Conservation Service, the Agricultural Stabilization and Conservation Service and the Cooperative Extension Service. It provides \$1,000,000 through the government funds as a cost-sharing program for building stacking sheds in the study area. Fifth, a litter quantity constraint is included in the model to ensure that the applied litter is less than or equal to the available litter. It was estimated that in the watershed 30,187 tons of poultry litter is produced annually. Sixth, a constraint on the available forage area was introduced. Davis et al. (1987) suggest that in accordance with the climate, soil fertility and grazing management in the study area, at least two times more acreage should be planted in tall fescue than bermudagrass in order to balance seasonal demands of a year-round cattle herd. Finally, a seventh constraint was placed on the rate of litter application per year to depict the current U.S. Co-operative Extension Service recommendations on litter application. The current recommendation requires that no more than 5 tons of litter can be applied to an acre of land per year with multiple applications restricted to 2.5 tons per acre per application (See Appendix A for a detailed description of the model).

The results are discussed in terms of each soil series in the watershed. Each of the scenarios is analyzed under "unconstrained maximization", "phosphorus management constraint" only, and "phosphorus management and rate constraints" conditions. The unconstrained maximization allows for production of bermudagrass and tall fescue on the available acres of the watershed. The "phosphorus management constraints" only category allows for cultivation of bermudagrass and tall fescue on those lands where the soil test P does not exceed 300 pounds per acre. The "phosphorus management and rate constraints" category allows for application of only 5 tons of litter per acre, per year in addition to the previous management condition. Also in the analysis, the effect of differences in the selling prices of the litter at \$7 or \$5 per ton or at the disposal cost of $\$-0.005$ per ton of litter for hauling is analyzed. The base price assumes that bermudagrass can be sold for \$50 per ton and tall fescue can be sold for \$25 per ton. In the case of the sensitivity analysis, high prices assume \$60 per ton of bermudagrass and \$40 per ton of tall fescue and low prices assume \$40 per ton of bermudagrass and \$20 per ton of tall fescue (Garner, 1993).

First, consider the base price effects on the marginal values of different soil series. With base prices for bermudagrass and tall fescue and with no constraint on phosphorus loadings, all the available litter was used for forage production. As a result, the marginal values of the soil series do not differ based on the selling price of the litter or the disposal cost of hauling the litter. The differences are due to the marginal productivity of each soil series. As can be seen from Table 1, the ten soil classes (including the aggregated minor soil series in the watershed) exhibit differences in the marginal value of an additional acre of land. There is a difference of $2.7 between the most valuable soil series and the least valuable soil series. That is by allocating the litter to soil series 16 instead of soil series 20, society as a whole can gain $2.7 per acre, provided the contribution towards groundwater contamination from these two acres are the same. Similar results are presented for the other scenarios in Table 1.

Second, consider the sensitivity analysis on the high output price for bermudagrass and tall fescue. With higher prices for bermudagrass at $60 ton^{-1} and for tall fescue at $40 ton^{-1}, the marginal value of additional acreage will naturally be higher than the base price results. In the case of unconstrained maximization, there is a difference of $10.20 between the highest marginal value of an additional acreage and the lowest marginal value of an additional acreage. In the case of "phosphorus management constraint" only, the difference between the highest marginal value and the lowest marginal value of soil series is $29.44. With both the "phosphorus management and rate constraints", again not only the marginal values of each soil series increases, but also the difference between the highest marginal value and the lowest marginal value of soil series increases. With low output prices for bermudagrass and tall fescue, the marginal value of additional acreage drops to about $4. There is no significant difference between the marginal values of additional acreage between different soil series. With phosphorus constraint only, there is a difference of $9.44 between the highest marginal value and the lowest marginal value of soil series. In the scenario with both phosphorus and rate constraint, with the selling prices of litter at $7 and $ − 0.005, there is a difference of $10.37 and $12.42 between the highest marginal value and the lowest marginal value of different soil series.

The results based on the marginal values of individual soil series indicate that the uniform control of litter application on different soil series is an inefficient way to control surface and groundwater contamination. If the contribution towards water quality is approximately the same from different soil series, then the management of litter application should take into account the

Table 1
Marginal values of soil series

Scenarios cost	Transportation	Soil series ($ per acre) [1]									
	($ ton^{-1})	0	6	11	16	17	18	20	23	28	31
Bermuda $50 ton^{-1} and Fescue $25 ton^{-1}											
Unconstrained max.	7/5/ − 0.005	10.65	11.57	8.87	8.87	11.57	9.95	11.57	11.57	11.57	11.03
P constraint only	7/5/ − 0.005	9.46	25.34	7.68	7.68	25.34	8.76	25.34	25.34	25.34	9.84
P and RATE constraint	7	13.81	32.50	12.03	12.03	32.50	13.11	32.50	32.50	32.50	14.29
	5	16.47	35.17	14.70	14.70	35.17	15.78	35.17	35.17	35.17	16.86
	− 0.005	20.04	38.73	18.26	18.26	38.73	19.34	38.73	38.73	38.73	20.42
Bermuda $60 ton^{-1} and Fescue $40 ton^{-1}											
Unconstrained max.	7/ − 0.005	23.44	26.91	16.71	16.71	26.91	20.79	26.91	26.91	26.91	24.87
P constraint only	7/ − 0.005	23.48	46.19	16.75	16.75	46.19	20.83	46.19	46.19	46.19	24.91
P and RATE constraint	7/ − 0.005	27.57	52.36	20.84	20.84	52.36	24.92	52.36	52.36	52.36	29.00
Bermuda $40 ton^{-1} and Fescue $20 ton^{-1}											
Unconstrained max.	7/ − 0.005	3.50	3.57	3.37	3.37	3.57	3.45	3.57	3.57	3.57	3.53
P constraint only	7/ − 0.005	1.55	10.86	1.42	1.42	10.86	1.50	10.86	10.86	10.86	1.58
P and RATE constraint	7	1.86	12.10	1.73	1.73	12.10	1.81	12.10	12.10	12.10	1.89
	− 0.005	10.28	22.57	10.15	10.15	22.57	10.23	22.57	22.57	22.57	10.31

[1] Soil series 0 represents the aggregated minor soil series, 6 Captina, 11 Enders, 16 Hector–Mountainburg, 17 Jay, 18 Johnsburg, 20 Linker, 23 Pembroke, 28 Savannah and 31 Summit.

marginal value of each soil series. Less litter should be allowed on soils with low marginal values than soil series with high marginal values to economically implement the environmental policy.

The usefulness of non-point source pollution control depends on two related considerations. The economic benefits of surface and groundwater contamination control from poultry litter must be weighed against the costly prediction, monitoring and control of non-point source pollution. On the benefit side, the regulation on land application of poultry litter not only controls phosphorus loadings but also other nutrients such as nitrogen and also bacterial contamination. Control of eutrophication in recreational areas associated with lakes and rivers could increase the indirect value derived by the society from clean environment. On the cost side, the regulator must find an acceptable balance between the objectives of reducing control costs and achieving water quality objectives with reliability.

5. Conclusions

This paper analyzes the economic implications of a proposed phosphorus management policy which would restrict the land application of poultry litter to soils with elevated phosphorus levels. The proposal would prohibit litter applications to soils which have soil test P in excess of 300 pounds per acre. It also develops a theoretical microeconomic model to analyze the efficiency of this policy. The optimal solutions are discussed in terms of each soil series in the watershed. Each of the soil series is analyzed in terms of the unconstrained maximization, phosphorus constraint only and phosphorus and rate constraints.

The optimal solutions indicate that there is a difference of \$2.70 with unconstrained maximization, \$17.66 with phosphorus management constraint only, and \$20.47 with both the phosphorus management and rate constraints in the marginal value between the most valuable and the least valuable soil series. The difference between the marginal values of most valuable and the least valuable soil series increases with higher prices for the forage crops bermudagrass and tall fescue. The existence of significant differences between the marginal values of poultry litter on different soil series suggests that more acres can be brought under environmental regulation by adopting a marketable permit system assuming that the carrying capacity of litter for the watershed can be defined and that transaction costs to create the market are not excessive.

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Appendix

The mathematical programming model can be divided into seven sections (Buchberger, 1991). First, the objective function maximizes the net returns over variable costs from various activities consisting of tall fescue and bermudagrass net of excess poultry litter transportation costs or benefits and storage cost of the litter. The objective function of the maximization problem can be represented as

$$\text{Max } \pi = \sum_{i=1}^{2} \sum_{j=1}^{10} \sum_{k=1}^{5} \sum_{l=1}^{4} \left[P_i Y_{i,j,k,l} - C_{i.k} \right] X_{i,j,k,l} - C_t T - C_s \sum_{i=1}^{2} \sum_{j=1}^{10} \sum_{k=1}^{5} \sum_{m=1}^{3} Q_m X_{i,j,k,m} \tag{A1}$$

where:

π	is profit
i	is grass species tall fescue or bermudagrass
j	is aggregated soil series
k	is rate of poultry litter application
l	is time period of litter application
P_i	is price of grass species i

$X_{i,j,k,l}$ is activity or acres of ith grass on jth soil, with kth rate of poultry litter application (0, 1, 2, 3, 4 tons/acre) in lth time period (fall, spring, summer and fall/spring)
$Y_{i,j,k,l}$ are yields associated with i, j, k, l th activity
$C_{i,k}$ is cost of producing ith grass with kth rate of poultry litter application (0, 1, 2, 3, 4 tons/acre)
C_t is cost of transporting poultry litter from the area ($ per ton)
T is the quantity of poultry litter that has to be transported from the area (tons)
C_s is the cost of building stacking sheds
Q_m is the litter that has to be stored and applied during mth period
$X_{i,j,k,m}$ are acres of ith grass on jth soil, with kth rate of poultry litter application in m time period

In each scenario, based on a survey on litter use in northwest Arkansas (Rutherford, 1993), three poultry litter price subscenario were analyzed: sale price of litter \$7 ton^{-1}; sale price of litter \$5 ton^{-1}; and disposal cost of litter \$-0.005 ton^{-1}. A set of base prices on bermudagrass and tall fescue were used to analyze the impact of phosphorus loadings constraint on profitability for the entire watershed. Second, the soil class acre constraints place an upper bound on the number of acres available on each of the ten soil series covering approximately 47 000 acres, out of which 29 950 acres are currently in pasture in the Muddy Fork watershed. The soil class constraint can be represented as

$$\sum_{i=1}^{2} \sum_{k=1}^{5} \sum_{l=1}^{4} X_{i,j,k,l} \leq A_j \tag{A2}$$

where A_j is the available acres of j_{th} soil. Third, the phosphorus management constraint limits the acres that are available for application after eliminating the excess P concentrated lands. This imposes additional restrictions on the soil class acre constraints. Fourth, the government cost-sharing in the projects is incorporated to analyze the impact on profit from the water quality special project. The program is a joint action of Soil Conservation Service, the Agricultural Stabilization and Conservation Service and the Cooperative Extension Service. It provides \$1 000 000 through the government funds as a cost-sharing program for building stacking sheds in the study area. The government cost-sharing program is represented as

$$\sum_{i=1}^{2} \sum_{j=1}^{10} \sum_{k=1}^{5} \sum_{l=1}^{4} X_{i,j,k,l} P \leq 1\,000\,000 \tag{A3}$$

where P is the government participation in the program ($ per acre). Fifth, a litter quantity constraint is included in the model to ensure that the applied litter is less than or equal to the available litter. It was estimated that in the watershed 30 187 tons of poultry litter was produced annually. The litter transport constraint can be symbolically represented as

$$\sum_{i=1}^{2} \sum_{j=1}^{10} \sum_{k=1}^{5} \sum_{l=1}^{4} (X_{i,j,k,l} PL_1) + T = M \tag{A4}$$

where:
PL_1 is quality of litter applied at level 1 (tons/acre)
M is quantity of litter produced in the watershed (tons).

Sixth, a constraint on the available forage area was introduced. Davis et al. (1987) suggest that in accordance with the climate, soil fertility and grazing management in the study area, at least two times more acreage should be planted in tall fescue than bermudagrass in order to balance seasonal demands of a year-round cattle herd. This pasture and forage availability constraint can be represented as

$$\sum_{F} \sum_{j=1}^{10} \sum_{k=1}^{5} \sum_{l=1}^{4} X_{F,j,k,l} \geq 2 * \sum_{B} \sum_{j=1}^{10} \sum_{k=1}^{5} \sum_{l=1}^{4} X_{B,j,k,l} \tag{A5}$$

Where, F represents the acres of tall fescue and B represents the acres of bermudagrass. Finally, a seventh constraint was placed on the rate of litter application per year to depict the current University of Arkansas Co-operative Extension Service recommendations on litter application. The current recommendation requires that no more than 5 tons of litter can be applied to an acre of land per year with multiple applications restricted to 2.5 tons per acre per application.

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