Implications of Policy Regulations on Land Applications of Poultry Litter

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The growth of the poultry industry in Arkansas has exploded in the past decade. As a result, approximately 1.5 million tons of litter are produced every year. Concerns about possible contamination of ground and surface water from land applications of poultry litter have been raised. This paper compares four policy scenarios in terms of their efficiency and practicality to manage land applications of poultry litter. The results indicate that a litter tax per ton of litter applied could achieve the same level of litter control as that of a land tax on litter applications, but at a lower tax rate.

Nonpoint source pollution created by agriculture is one of the most damaging and widespread threats to a clean environment (National Research Council 1989). Activities such as excessive fertilizer and pesticide applications and improper animal waste management have gained attention in the recent past (Prato, Xu, and Jenner 1992a, 1992b, 1992c, 1992d; Prato et al. 1991). The growth of the poultry industry in Arkansas has exploded in the past decade. Approximately 24 million chickens, 25 million turkeys, and 1 billion broilers are produced every year in the state (Buchberger, Cochran, and Govindasamy 1993; Govindasamy and Cochran 1995a, 1995b). As a result, approximately 1.5 million tons of litter are produced every year. Most poultry litter in northwest Arkansas, the region with the greatest poultry concentrations, is applied as a fertilizer to nearby pasture lands consisting of bermuda grass and tall fescue (Cochran and Govindasamy 1994; Cochran et al. 1993).

Concentrated litter production may result in litter applications that exceed the nutrient requirements of the local forage, creating a potential to contaminate surface and groundwater (Govindasamy et al. 1994; Govindasamy and Cochran 1994). Concerns have been expressed about possible contamination by nitrates, phosphorus, and bacteria in water arising from land applications of litter (Xu and Prato 1995; Xu, Prato and Fulcher 1993; Xu and Prato 1993, 1992).

In northwest Arkansas, the number of wells with N-nitrate levels above the maximum contamination level (MCL) of 10 ppm has increased in the past few years (Steele, McCallister, and Adamski 1990). In this same period, the poultry industry experienced substantial growth. A summary of Arkansas water mineral quality data, in 1971 and 1972, reported less than 2.2% of the sample wells tested were above the MCL for nitrates, whereas, in 1986, 14% of the tested wells were above the MCL (Madison and Brunett 1985). The Arkansas nonpoint source pollution assessment concluded from 1988 monitoring data that in the Ozark Highlands region, ''nitrate levels . . . are consistently high and few streams meet the primary contact recreational standards due to high fecal coliform concentrations'' (Arkansas Department of Pollution Control and Ecology 1990).

There is a need to analyze the alternative litter management policies to prevent problems from nitrate (N), phosphorus (P), and bacterial loadings. Although there exist numerous policy tools such as taxes, permits, and quantity restrictions to control land applications of poultry litter, only some are suitable for a given environment. The efficiency of each of these possible tools and their practicality in the real world should be examined before implementation. The objective of this paper is to compare four policy scenarios in terms of their efficiency, impact on litter use, and practicality to manage land applications of poultry litter. These include (1) a per ton litter tax; (2) a land tax on litter applications; (3) a quantity restriction on litter applications and land treated with litter; and (4) a permit system to control litter applications and land treated with litter. A programming model is linked with a Geographic Information System with

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an objective of maximizing the regional forage income. The model also incorporates the option of transporting the litter to areas that are less sensitive to surface and groundwater contamination.

Methods

A programming model is formulated using the General Algebraic Modeling System (GAMS) (Brooke, Kendrick, and Meerus 1988). The objective function in this model maximizes regional forage income from the Muddy Fork watershed of the Illinois River in Washington County in northwest Arkansas. Based on previous studies (Govindasamy, Cochran, and Buchberger 1994), it is assumed that bermuda grass can be sold for $50 per ton and tall fescue can be sold for $25 per ton. 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 Department of Agronomy at the University of Arkansas, Fayetteville (Scott et al. 1992). 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). In terms of physical characteristics of the soil, Captina, Jay, and Pembroke belong to silt loam with 1–3% slope; Johnsburg belongs to silt loam with 0 slope; Enders belongs to gravelly loam with 3–8% slope; Hector-Mountainburg belongs to gravelly fine sandy loams with 3–8% slope; Linker belongs to loam with 1–3% slope; Savannah belongs to fine sandy loam with 1–3% slope; and Summit belongs to silty clay with 0–1% slope.

The inputs to the programming model were derived from field experiments and standard budgeting. The budgeting of profits per acre was carried out using field experimental data on yield, input costs, and output prices of bermuda grass and tall fescue on ten different soil series, with five different application rates (0, 1, 2, 3, and 4 tons per acre), and four different times of litter application (spring, summer, fall, fall/spring [implies application in both fall and spring]). Budget data calculations were based upon experimental yield responses, Cooperative Extension Service (CES) budgets, and Soil Conservation Service (SCS) productivity indices. Extrapolations from actual experimental yields using SCS productivity indices were necessary to cover all the range of soil classes, rates, and times of application. The yield response data collected form the field experiments take into account the fertility status of the soils depending on the level of nutrients such as phosphorus, nitrogen, and potassium.

The baseline mathematical programming model can be divided into five sections (Buchberger 1991). First, the objective function maximizes the regional forage income over variable costs from various activities consisting of tall fescue and bermuda grass net of poultry litter storage costs. The objective function of the maximization problem can be represented as

(1)

$$\text{Max } \pi = \sum_{I=1}^{2}\sum_{j=1}^{10}\sum_{k=1}^{5}\sum_{l=1}^{4} [P_i Y_{i,j,k,l} - C_{i,k}] X_{i,j,k,l} + AT - C_s \sum_{I=1}^{2}\sum_{j=1}^{10}\sum_{k=1}^{5}\sum_{m=1}^{3} Q_m X_{i,j,k,m},$$

where

π	is regional forage income
I	is grass species, either tall fescue or bermuda grass
j	is aggregated soil series
k	is rate of poultry litter application
l	is time period of litter application
m	is storage time
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 per acre) in lth time period (fall, spring, summer, and fall/spring)
$Y_{i,j,k,l}$	are yields associated with ith, jth, kth, lth activity
$C_{i,k}$	is cost of producing ith grass with kth rate of poultry litter application (0, 1, 2, 3, 4 tons per acre)
A	is opportunity cost of poultry litter in the local market ($ per ton)
T	is the quantity of poultry litter that has to be transported from the area, which is equal to total supply of litter minus total amount applied to pasture (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
$X_{i,j,k,m}$	is acres of ith grass on jth soil, with kth rate of poultry litter application in m time period.

The variable $X_{i,j,k,l}$ is optimized for profit. That is, the model would choose the forage crop, soil type, poultry litter rate, and the time period of application to maximize the profit, subject to stated constraints. In each scenario, based on a survey on litter use in northwest Arkansas (Rutherford 1993), two poultry litter price subscenarios or opportunity cost (A) were analyzed: (1) sale price of litter $7 per ton and (2) disposal cost of litter $0 per ton. The sale price of litter at $7 per ton represents the practice of selling litter to neighboring farmers, whereas $0 disposal cost represents the practice of trading litter for poultry housecleaning.

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. The soil class constraint can be represented as

$$(2) \qquad \sum_{l=1}^{2}\sum_{k=1}^{5}\sum_{l=1}^{4} X_{i,j,k,l} \le ACRE_j,$$

where $ACRE_j$ is the available acres of jth soil.

Third, the government cost-sharing in the project is incorporated to analyze the impact of the water quality project on regional forage income. The program is a joint action of the Natural Resources Conservation Service (NRCS), the Agricultural Stabilization and Conservation Service (ASCS), and the CES. It provides about $1 million through government funds as a cost-sharing program for building stacking sheds in the study area. The government cost-sharing program is represented as

$$(3) \qquad \sum_{l=1}^{2}\sum_{j=1}^{10}\sum_{k=1}^{5}\sum_{l=1}^{4} X_{i,j,k,l}\, G \le 1{,}000{,}000,$$

where G is the government participation in the program ($ per acre). The model requires poultry growers to build stacking sheds with capacity for storing 100 tons of poultry litter per year. The program covers 75% of building costs, and the rest is provided by farmers. The stacking sheds not only minimize the loss of nutrients from the litter but also allow growers to apply litter at times other than immediately following the traditional clean out, thus reducing the potential surface and groundwater contamination.

Fourth, 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 litter are produced annually. The litter use constraint can be symbolically represented as

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

where

- PL_k is rate of litter applied at level k (tons per acre)
- T is the quantity of poultry litter that has to be transported from the area (tons)
- M is quantity of litter produced in the watershed (tons).

Fifth, 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 bermuda grass in order to balance seasonal demands of a year-round cattle herd. This pasture and forage availability constraint can be represented as

$$(5) \qquad \sum_{j=1}^{10}\sum_{k=1}^{5}\sum_{l=1}^{4} X_{F,j,k,l} \ge 2^* \sum_{j=1}^{10}\sum_{k=1}^{5}\sum_{l=1}^{4} X_{B,j,k,l},$$

where F represents tall fescue and B represents bermuda grass.

Alternative policy scenarios were constructed consisting of a tax per ton of litter applied; a tax per acre of land treated with litter; a quantity restriction on litter applications and land treated with litter; and a permit system for litter applications.

The Pigouvian litter tax scenario introduces a per unit tax on litter use for crop production, whereas the land tax introduces a tax on land treated with poultry litter. The use of such taxes can eliminate the difference between the marginal social cost and marginal private cost schedules of a farm responsible for an external diseconomy. The use of tax instruments restructures the policy information requirements from persistent monitoring for efficient point-to-point regulation to data that ensure that tax rates reflect marginal social costs. However, it should be noted that the marginal social costs are often not known, so the optimal Pigouvian tax cannot be determined. Therefore, the amount of externality that gets internalized by an arbitrary tax may not be optimal.

In terms of efficiency criteria, taxes can internalize external costs directly to producers and consumers of products responsible for environmental deterioration. Although taxes are appealing from an efficiency perspective, significant business opposition exists to any environmental taxation policy. The roots of this opposition are, fundamentally, the distributional effects of taxes, the fall in output, higher prices, and a decrease in profits (Seneca and Taussig 1974).

If a tax policy is implemented, it should be easy to administer compared with other policies. We examine a per ton litter tax and a land tax on litter applications in terms of a favorable environment for implementation and monitoring. A tax on litter is difficult to monitor, whereas a tax on land can be relatively easier to monitor. In both the litter tax and the land tax we use three opportunity costs of litter in the local market and three litter tax rates/land tax rates to analyze the impact of policy on optimal use.

Centrally planned and directed environmental policy tools such as Pigouvian taxes and subsidies often not only require information but also raise difficulties for the calculation of optimal tax rates. Estimation of the money value of the marginal damage to impose optimal taxes or subsidies is hindered by the various limitations to the estimation of damage to human health and the environment. The use of a predetermined standard or quantity restriction is another environmental policy tool that can be based on health and safety considerations.

The use of taxes, subsidies, or marketable permits possesses one important property. That is, under appropriate conditions, these policy tools can achieve environmental goals at a least cost. Consider the case of poultry litter. Suppose that the litter application has to be constrained to X tons in a watershed consisting of two soil types that have the same marginal damage function. A litter application quantity restriction would imply that each soil type should be constrained to receive not more than $X/2$ tons of litter. However, it may be a costlier solution, if the marginal values of the two soils are not equal. To achieve efficiency, the soil with low marginal value should be assigned a lower quota (in other words, less than $X/2$ tons of litter) than the soil with high marginal value.

Now consider the properties of marketable permits to control environmental pollution. In general, the marketable permit system idea is appealing from the efficiency point of view because it possesses the least-cost property (Baumol and Oats 1988). The marketable permit system defines property rights for environmental resources and then offers them for sale to the highest bidder (Dales 1968). The permit system has some advantages over effluent fees for the attainment of a set of predetermined environmental standards. First, a 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 the introduction of the scheme, a permit system can be introduced smoothly 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 systems. First, it might be cumbersome to establish the carrying capacity of the watershed in terms of pounds of litter that can be applied. Second, 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. Third, it might be difficult to control overapplication of poultry litter on environmentally sensitive lands, especially when that land has a high value of marginal product (VMP) of litter. Since the permits are tradable, only those producers with high VMP of litter can afford to buy the permits at a high price. Finally, some may object to marketable permits since they are viewed as a license to pollute.

The baseline scenario depicts the simulation without any restriction on poultry use or land treated with litter. It should be noted that a tax on land treated with litter would be easier to monitor than a tax on litter applications. Tax on litter applications could be approximated by a per bird tax, which has been suggested in the past. A per ton litter tax was introduced by modifying the objective function as follows:

(6)

$$\text{Max } \pi = \sum_{I=1}^{2}\sum_{j=1}^{10}\sum_{k=1}^{5}\sum_{l=1}^{4} [P_i Y_{i,j,k,l} - C_{i,k}]X_{i,j,k,l} + AT - C_s \sum_{I=1}^{2}\sum_{j=1}^{10}\sum_{k=1}^{5}\sum_{m=1}^{3} Q_m X_{i,j,k,m} - \text{TLIT} \sum_{I=1}^{2}\sum_{j=1}^{10}\sum_{k=1}^{5}\sum_{l=1}^{4} (X_{i,j,k,l} PL_k),$$

where TLIT represents the unit tax on litter applied. As can be seen from equation (6), an increase in the tax on litter reduces the regional forage income, forcing the optimal solution to choose a practice with low litter application rate.

A land tax on litter applications was introduced by modifying the objective function as follows:

(7)

$$\text{Max } \pi = \sum_{I=1}^{2}\sum_{j=1}^{10}\sum_{k=1}^{5}\sum_{l=1}^{4} [P_i Y_{i,j,k,l} - C_{i,k}]X_{i,j,k,l} + AT - C_s \sum_{I=1}^{2}\sum_{j=1}^{10}\sum_{k=1}^{5}\sum_{m=1}^{3} Q_m X_{i,j,k,m} - \text{TLAND} \sum_{I=1}^{2}\sum_{j=1}^{10}\sum_{k=2}^{5}\sum_{l=1}^{4} (X_{i,j,k,l}),$$

where TLAND represents the land tax on litter applications. As can be seen from equation (7), the third term with a negative sign imposes a tax on every acre of land treated with litter. Note that the k is summed from 2 to 5 so that a land tax is not imposed when litter is not applied. Parallel to equation (6), a tax on land reduces the incentive to apply litter to many acres. Although it is possible to impose a land tax based on the carrying capacity of the soils, we limit our analysis to a single tax so that the results can be compared with a single litter tax.

The quantity restriction was introduced in two ways. First, a restriction on the quantity of litter applied was introduced for each of the ten soil series as follows:

$$(8) \quad \sum_{l=1}^{2}\sum_{k=1}^{5}\sum_{l=1}^{4} (X_{i,j,k,l}PL_k) \leq \text{CARCAP}_j,$$

where CARCAP represents the carrying capacity of each soil series in the watershed. The carrying capacity of soil series was estimated based on Scott, Mauromoustako, and Gilmour's study (1994) of phosphorus uptake of pasture lands. Equation (8) introduces a limit on the maximum use of litter for each soil series. Second, a restriction on the amount of land treated with litter was introduced for each of the ten soil series as follows:

$$(9) \quad \sum_{l=1}^{2}\sum_{k=1}^{5}\sum_{l=1}^{4} (X_{i,j,k,l})/(k > 1) \leq \text{PLIMIT}_k,$$

where PLIMIT_k represents the number of acres that is capable of receiving litter applications based on the soil test phosphorus for each soil type.

A permit system was also introduced in two ways. First, a permit system for the use of litter in each soil series was introduced as follows:

(10)

$$\sum_{l=1}^{2}\sum_{j=1}^{10}\sum_{k=1}^{5}\sum_{l=1}^{4} (X_{i,j,k,l}PL_k) \leq \sum_{j=1}^{10}\text{CARCAP}_j.$$

Equation (8) places a constraint on litter applications for each soil series, whereas equation (10) places a constraint on litter applications for the entire watershed because the permits are tradable within the watershed. Second, a permit system for land treated with litter was introduced for each of the ten soil series as follows:

(11)

$$\sum_{l=1}^{2}\sum_{j=1}^{10}\sum_{k=1}^{5}\sum_{l=1}^{4} (X_{i,j,k,l})/(k > 1) \leq \sum_{j=1}^{10} \text{PLIMIT}_k.$$

Parallel to equations (8) and (10), equation (9) places a constraint on land treated with litter for each soil series, whereas equation (11) places a constraint on land treated with litter for the entire watershed. That is, the permit system would allow for the choice of land treated with litter within the watershed, whereas the quantity restriction will limit the choice within each soil series.

Results

The results are discussed in terms of four scenarios: (1) per ton litter tax scenario; (2) land tax on litter applications scenario; (3) quantity restriction scenario; and (4) permit scenario.

Per Ton Litter Tax Scenario

The litter tax scenario is analyzed in terms of the entire watershed as well as the individual soil series. We assume that the litter either can be sold at a price (opportunity cost of litter) of $0, $2.50, $5, or $7 per ton of litter, or can be used for crop production with a Pigouvian tax on litter applied for crop production at $0, $5, $10, or $15 per ton. The Pigouvian tax rates were chosen in such a way that the optimal litter use is comparable to quantity restrictions. That is, the optimal litter use after the litter tax is similar to imposed quantity restriction.

As a result, one can compare the cost of litter restriction between two policy tools, given that the litter applied is the same. The upper bound on the opportunity cost of litter at $7 per ton was chosen based on a survey of poultry producers conducted in Arkansas (Rutherford 1993). The results of the entire watershed analysis are presented in table 1. When the opportunity cost of litter was $0, with no tax on litter, it was optimal to apply all the litter at an average rate of 3.02 tons per acre.

When the opportunity cost of litter was $0, the solution indicated that the optimal rate of litter application remained at 3.02 tons per acre with a litter tax rate of $5, $10, or $15 per ton. When the opportunity cost was $2.50 per ton of litter, the optimal solution did not change at a litter tax rate of $5 and $10 per ton. However, when the litter tax rate increased to $15 per ton, the optimal litter use dropped to 2 tons per acre. Approximately 34% of the litter was sold in the market at a price of $2.50 per ton of litter. With an increase in the opportunity cost of litter use to $5 per ton, the optimal solution indicated that all the litter should be used for crop production at a tax rate of $5 and $10 per ton. With a tax rate of $15 per ton of litter, it was optimal to sell all the litter in the market at a price of $5 per ton.

When the opportunity cost increased to $7 per ton of litter, with a tax rate of $5 per ton of litter, it was optimal to use all the litter for crop production. However, when the tax rate increased to $10 per ton, it was optimal to apply only 2 tons per acre. At the same opportunity cost, when the tax rate increased to $15 per ton of litter, it was not optimal to use any litter for crop production within

Table 1. Impacts of Tax on Litter

Opportunity Cost[a] ($/ton)	Tax on Litter ($/ton)	Litter Use (tons)	Litter Treated Area (acres)	Litter Transported (tons)	Litter Use Per Acre (tons/acre)	Tax Revenue ($/watershed)
0	0	30,187	9,983	0	3.02	0
0	5	30,187	9,983	0	3.02	150,940
0	10	30,187	9,983	0	3.02	301,870
0	15	30,187	9,987	0	3.02	452,810
2.5	5	30,187	9,987	0	3.02	150,940
2.5	10	30,187	9,987	0	3.02	301,870
2.5	15	19,966	9,983	10,220	2.00	299,500
5	5	30,187	9,983	0	3.02	150,940
5	10	30,187	9,983	0	3.02	301,870
5	15	0	0	30,187	0	0
7	5	30,187	9,983	0	3.02	150,940
7	10	19,966	9,983	10,220	2.00	199,660
7	15	0	0	30,187	0	0

[a]Opportunity cost represents the selling price of litter in the local market.

the watershed. The tax revenues varied considerably by tax rates and the opportunity cost of litter. At high opportunity costs, tax revenues are maximized at a tax rate of $10 per ton. As expected, the increase in tax rates reduced the use of litter in the watershed for a given level of the opportunity cost of the litter. The increase in the opportunity cost of litter for a given level of tax rate also encourages reduction in litter use within the watershed, since there are viable economic alternatives to local land applications of litter.

Consider the impact of changes in tax rates and the opportunity cost of litter on the individual soil series optimal solutions. The choice set of the optimal litter application rates in the case of individual soil series were reduced to 0, 2, and 4 tons per acre to analyze the changes in the optimal solutions for a change in the tax rate. Although the increase in tax rates decreases the optimal litter use for the entire watershed, the change in the optimal litter use in each of the soil series depends on the relative VMP of litter in different soil series. The optimal solutions for five soil series among the ten remained unchanged at all tax rates and opportunity cost of litter.

In the rest of the soil series, while the litter use increased with tax increases in some soil series, in others, the litter use decreased. It should be noted that cycling of the optimal solutions occurred with increased taxes due to the nature of profit functions and the relative VMP of litter in different soil series. No general conclusions can be reached about the impact of taxes on the intensity of litter use in each soil series as the potential for cycling will be determined by specific profit functions, making it an empirical question for each watershed.

Land Tax on Litter Applications Scenario

The land tax scenario is also discussed in terms of the entire watershed and individual soil series. As in the litter tax scenario, we assumed that the litter either can be sold at a price (opportunity cost of litter) of $0, $2.50, $5, or $7 per ton of litter, or can be used for crop production with a tax on land treated with litter of $0, $50, $75, or $100 per acre. The land taxes were chosen in such a way that the optimal litter uses are comparable to quantity restrictions. As expected, although a tax on land reduced the number of litter-treated acres, it increased the optimal use of litter per acre.

First, consider the entire watershed. The results are presented in table 2. When the opportunity cost of litter was $0, a land tax of $50 and $75 per acre reduced the litter treated land by 50% and 38%, respectively. However, all the litter was being used for crop production, with an increase of 8 tons per acre in the litter application rate. When the land tax increased to $100 per acre, the optimal solution indicated that it is not optimal to apply any litter for crop production within the watershed.

When the opportunity cost of litter use increased to $2.50 from $0 per ton, the optimal solutions remained the same. With an opportunity cost of $5 per ton of litter, the litter use remained the same at a tax rate of $50 per acre. However, with a tax rate of $75 and $100 per acre, it was not optimal to apply any litter for crop production within the watershed. With an opportunity cost of litter at $7 per ton, it was not optimal to apply any litter within the watershed at any of the three tax rates. Once again tax revenues vary considerably with rates and the opportunity cost of the litter.

Table 2. Impacts of Tax on Land Treated with Litter

Opportunity Cost[a] ($/ton)	Tax on Littered Land ($/acre)	Litter Use (tons)	Litter Treated Area (acres)	Litter Transported (tons)	Litter Use Per Acre (tons/acre)	Tax Revenue ($/watershed)
0	0	30,187	9,983	0	3.02	0
0	50	30,187	5,031	0	6.00	251,560
0	75	30,187	3,773	0	8.00	283,010
0	100	0	0	30,187	0.00	0
2.5	50	30,187	5,031	0	6.00	251,560
2.5	75	30,187	3,773	0	8.00	283,000
2.5	100	0	0	30,187	0.00	0
5	50	30,187	5,031	0	6.00	251,560
5	75	0	0	30,187	3.02	0
5	100	0	0	30,187	0.00	0
7	50	0	0	30,187	0.00	0
7	75	0	0	30,187	0.00	0
7	100	0	0	30,187	0.00	0

[a]Opportunity cost represents the selling price of litter in the local market.

Consider the impact of changes in land taxes on individual soil series. Compared with the litter taxes, the optimal solutions are relatively insensitive to changes in land taxes and the opportunity cost of litter. Because of the nature of the land tax, it is optimal to apply either 8 tons per acre or none depending on the level of taxes and opportunity costs. As with the litter taxes, cycling of the optimal solutions also occurred in the land taxes because of the nature of the profit functions of different soils and the relative VMP of litter in different soil series.

Quantity Restriction Scenario

The quantity restriction scenario consisted of a restriction on the amount of litter applied or a restriction on the land treated with litter. First, consider the restriction on the amount of litter applied on each of the ten soil series. The restriction on the quantity of litter was derived based on the plant uptake of phosphorus and the phosphorus content of litter, because phosphorus is often cited as the most limiting nutrient in local water bodies. This limits the phosphorus loading to an amount roughly equivalent to plant uptake. The phosphorus uptake by the pasture land is about 71.50 pounds per acre per year, and litter contains about 1.88% of phosphorus (Scott, Mauromoustakos, and Gilmour 1994). Hence, the carrying capacity of each soil series is about 3,803 pounds of litter per acre.

The restriction on litter quantity was binding on some soil series (table 3). The optimal litter rates ranged from 0 to 4 tons per acre depending on the soil series. The total acres treated with litter and the total litter use remained the same, whereas the maximized regional forage income declined by 6% compared with unconstrained maximization. The quantity restriction distributes the litter among all soil series, whereas the unconstrained maximization distributes the litter to the most productive soils.

Second, consider the restriction on the land treated with litter. The restriction placed on the land was based on a soil phosphorus test survey in the study area (Govindasamy, Cochran, and Buchberger 1994). It indicates that, on average, 74% of acres under each soil series does not exceed the soil test P of 300 pounds per acre. The optimal solution indicates that, although the constraint on the land treated with litter is binding only for some soils, all available litter is used in the watershed (table 4). Therefore, restriction based on the soil test P content allows for only redistribution of the litter with no reduction in total litter use. When compared with the unconstrained maximization, the total acres treated with litter declined to 79% and the maximized regional forage income declined to 97% with no change in the litter use. The optimal rates of litter application ranged from 0 to 4 tons per acre, as opposed to 0 to 8 tons per acre in the case of restriction on the litter use.

Permit Scenario

The permit scenario deals with permits that are tradable within the watershed. Permit systems can consist of issuing either permits to apply litter or permits to limit the land treated with litter. The

Table 3. Optimal Solutions for Quantity Restriction vs. Permit System for Poultry Litter

Soil Class	% Slope	Available Acres	Optimal Permit Acres	Optimal Quantity Restriction Acres
Captina	1–3%	2903	2903/B/SP/4[a]	1379/B/SP/4 1524/F/FL/0
Enders	3–8%	1467	1467/F/FL/0	1467/F/FL/0
Hector-Mountainburg	3–8%	2526	2526/F/FL/0	2526/F/FL/0
Jay	1–3%	1622	1622/B/SP/4	1541/B/FLSP/2 81/F/FL/0
Johnsburg	———	1919	1919/F/FL/0	1215/B/SP/3 703/F/FL/0
Linker	1–3%	1470	1470/B/FLSP/2	1397/B/FLSP/2 74/F/FL/0
Pembroke	1–3%	1629	585/B/SP/4 695/B/FLSP/2 349/F/FL/0	774/B/SP/4 855/F/FL/0
Savannah	1–3%	2708	2708/B/FLSP/2	622/B/SP/4 1327/B/FLSP/2 758/F/FL/0
Summit	0–1%	2131	2131/F/FL/0	2131/F/FL/0
Others	———	11576	11576/F/FL/0	1728/B/SP/4 9848/F/FL/0
Total acres under litter			9983	9983
Total litter use (tons)			30187	30187
Maximized income for the watershed ($)			775780	731240

[a]The codes for the optimal solutions are: B = bermuda, F = fescue, SP = spring application, FL = fall application, and FLSP = fall and spring applications. The last number represents the litter application rate.

number of permits to be issued for litter use and for the land treated with litter was based on the quantity restriction scenario. That is, the restriction on the level of litter application and restriction on the land treated with litter are the same as that of the quantity restriction scenario for the entire watershed. But, in terms of individual soil series, there was no restriction on the amount of litter applica-

Table 4. Optimal Solutions on Quantity Restriction vs. Permit System for Land Treated with Poultry Litter

Soil Class	% Slope	Available Acres	Optimal Permit Acres	Optimal Quantity Restriction Acres
Captina	1–3%	2903	2903/B/SP/4[a]	625/B/FL/0 1858/B/SP/4 420/F/FL/0
Enders	3–8%	1467	1467/F/FL/0	1467/F/FL/0
Hector-Mountainburg	3–8%	2526	2526/F/FL/0	2526/F/FL/0
Jay	1–3%	1622	1622/B/SP/4	1038/B/SP/4 584/F/FL/0
Johnsburg	———	1919	1919/F/FL/0	1228/B/SP/3 691/F/FL/0
Linker	1–3%	1470	1470/B/FLSP/2	529/B/FL/0 941/B/SP/4
Pembroke	1–3%	1629	585/B/SP/4 695/B/FLSP/2 349/F/FL/0	1043/B/SP/4 587/F/FL/0
Savannah	1–3%	2708	2708/B/FLSP/2	975/B/FL/0 1733/B/SP/4
Summit	0–1%	2131	2131/F/FL/0	2131/F/FL/0
Others	———	11576	11576/F/FL/0	11562/F/FL/0 13/B/SP/0
Total acres under litter			9983	7854
Total litter use			30187	30187
Maximized income for the watershed			775780	749180

[a]The codes for the optimal solutions are: B = bermuda, F = fescue, SP = spring application, FL = fall application, and FLSP = fall and spring application. The last number represents the litter application rate.

tion and land treated with litter. As a result, the constraint for the entire watershed is more relaxed than a quantity constraint for each soil series depicting the tradable permit system. With tradable permits, although the limit on maximum litter application level and land constraints are the same for the entire watershed as that of quantity restriction, the system redistributes the litter to soils with the highest VMPs.

First, consider the permit system for the use of litter. The number of permits to be issued will be equal to the tons of litter to be applied for the entire watershed. The limit on the tons of litter to be applied for the entire watershed was arrived at in a fashion similar to the quantity restriction scenario. The results of this scenario are presented in table 3. The optimal solution indicates that the total acres treated with litter, the total litter used in the watershed, and the maximized regional forage income is the same as that of the unconstrained solutions.

Second, consider the permit system for the land treated with litter. The permit system for the land treated with litter for the entire watershed was also derived in a way similar to the quantity restriction scenario. In fact, with the same restriction on land treated with litter, there was no change in the optimal solutions compared with unconstrained maximization solutions under the permit system. In comparison with the quantity restriction scenario, the total acres treated with litter increased by 27%, the maximum regional forage income increased by 4%, while the total litter use remained unchanged. The saved income from the permit system could serve as an upper boundary on transaction costs.

Conclusions

This paper examines four litter management policies in terms of their efficiency, impact on optimal litter use, and practicality in implementation. We use a linear programming model to formulate the regional forage income maximization problem for the Muddy Fork watershed of the Illinois River in northwest Arkansas.

With $0 opportunity cost and a tax rate of $0, $5, $10, or $15 per ton of litter, the optimal rate of litter application was unchanged at 3.02 tons per acre. When the opportunity cost of litter was increased to $2.50 per ton, the optimal litter use dropped to 2 tons per acre at litter tax of $15 per ton. With $0 opportunity cost of litter, a land tax of $50, $75, and $100 per acre, reduced the litter treated land by 50%, 38%, and 0% respectively. With an opportunity cost of $7 per ton, it was not optimal to apply any litter at any of the three tax rates. The results indicate that a tax per ton of litter applied could achieve the same level of litter control as that of a land tax on litter applications at a lower tax rate. Although a lower tax rate causes less distortion in the economy, it is more difficult to monitor a litter tax than a land tax.

Quantity restriction was imposed through either a restriction on the amount of litter applied or a restriction on the land treated with litter. With the restriction on the quantity of litter applied, the optimal litter rates ranged from 0 to 4 tons per acre depending on the soil series. With the restriction on the land treated with litter, the total acres treated with litter declined to 79% and the maximized regional forage income declined to 97% with no change in the litter use when compared with unconstrained maximization. In the case of a permit system for the land treated with litter, the total acres treated with litter increased by 27%, and the maximum regional forage income increased by 4% when compared with the quantity restriction scenario. The results also indicate that a permit system could achieve the same level of litter control as a quantity constraint, but at a lower cost to growers as indicated by the regional forage income.

The analysis assumes that land is used for fescue and bermuda grass production. The change in production costs, output prices, and litter output from poultry production in the watershed may affect the optimal solutions. The impact of distribution of litter in the watershed and the transaction costs associated with the permit system should also be considered before implementation.

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