Land Application of Broiler Litter to Protect Water Quality

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Abstract

An optimization model is developed which selects broiler litter management practices that maximize total net returns to land and management and estimates economic value of litter as a fertilizer substitute for an agricultural watershed experiencing rapid growth in broiler production. Results indicate that litter is an inexpensive substitute for commercial fertilizer and that litter value varies with the nutrient basis used to determine application rates, litter cleanout schedule and litter availability. Nutrients in current litter amounts do not exceed crop nutrient requirements, but would equal crop requirements if broiler production is doubled (tripled) and litter application rates are determined on a phosphate (nitrogen or potash) basis.

Introduction

The U.S. broiler industry is expanding. The Food and Agriculture Policy Research Institute forecast a 12 percent growth in broiler production by 1994. Missouri broiler industry is also expanding. The Missouri Department of Natural Resources estimates an increase in broiler production in Missouri from 127 million birds in 1989 to 245 million birds in 1995. Besides rapid growth in production,
concentration of broiler production becomes higher and higher due to vertical integration in broiler production.

As broiler production expands and becomes more concentrated, so does broiler litter. Broiler litter application to land has been a major use of broiler litter. Increasing concern about surface and ground water quality has focused attention on litter management in areas that have high litter concentration and high potential for surface and ground water contamination. Water quality can be negatively affected by excessive litter application. Water quality problems occur when nutrients in commercial fertilizer or broiler litter are applied to farmland in amounts that exceed crop requirements. Southwestern Missouri is a region with high litter concentration and karst topography which makes groundwater in the region highly vulnerable to pollution from nutrients in litter.

This paper examines the economic implications of efficient litter management in a Missouri watershed with potentially high litter concentration. Emphasis is on evaluating optimum crop requirements for broiler litter in the watershed and economic value of broiler litter. Specific objectives are to determine the optimal allocation of broiler litter to crops on different soil types; to estimate the maximum capacity for broilers in the watershed; and to estimate the economic value of broiler litter under current market conditions.

Procedures and Methods

A Geographic Information System (GIS) is used to store and analyze land use, soil type, slope, and other landscape attributes for Shoal Creek watershed, which is
located in Barry county, Missouri. Total area of the watershed is 42,564 acres, of which 33,884 acres are in grass and pasture, and 3,001 acres are in row crops. Land in grass, pasture and row crops accounts for more than 86 percent of the area. The remaining 14 percent is in forest, savannah, old fields, urban uses, orchards, Georges' broiler processing plant, and water (Prato et al. 1991a, and 1991b). Broilers, cattle (cow-calf) and dairy are the major livestock activities. Litter from broilers is applied to land in row crops, hay and pasture. Karst features (losing streams and sinkholes) make the area vulnerable to surface and ground water contamination from broiler litter.

The watershed is divided into soil types based on soil survey information. Acreage distribution by soil types is estimated using the GIS. Two dominant soil types, Sholten Gravelly Silt Loam and Tonti-Scholten Complex, are suitable for grass and pasture. They account for 72 percent of total acreage in crops, hay and pasture.

Seven possible crops were considered: grain sorghum, winter wheat, alfalfa, fescue hay, fescue pasture, switchgrass and bermudagrass. Since grain sorghum and winter wheat are currently planted in a very limited area (about 1,500 acres in Barry county in 1989), these crops were not considered. Switchgrass is not common in the area and is also excluded. Bermudagrass was excluded because it is not suited to the two dominant soils. The generally poor soils in the watershed are not well suited for alfalfa hay production. Therefore, the 3,001 acres in row crops were assumed to be in hay or pasture crops. Average hay and pasture yields on each soil type, obtained from the Barry county soil survey, were adjusted based on current practices in the watershed.
Information on nutrient content of broiler litter was obtained from a study which sampled and analyzed litter taken from broiler houses in Barry county (Prato et al. 1991b). Missouri litter is comparable to litter from other areas except for a higher phosphate content (Bosch and Napit, and Payne et al.). Average nutrient values for the sampled litter are used in the analysis. Options for removing litter from a broiler house include cleanout after 3, 4, 5 or 6 flocks. Litter cleanout is the removal of accumulated broiler manure and litter from the house. Quantity and nitrogen (N) content of litter varies with cleanout schedules. However, phosphate (P) and potash (K) content are similar for all cleanout schedules. Current amount of broiler litter in the watershed is estimated by multiplying the number of broiler houses currently in the watershed by the average annual amount of litter per house based on 5.5 flocks annually per house.

Crop nutrient requirements for N, P and K were estimated for fescue hay and pasture in each soil type for each of the four yield goals. Nutrients can be supplied by either commercial fertilizer or broiler litter. Detailed procedures for estimating crop nutrient requirements are provided in Buchholz. Nutrient requirements vary with soil (observed P and K levels in soil, $O_p$ and $O_k$) and yield goal (YG). For example, on Scholten soil, N, P and K requirements can be estimated for four yield goals using the following equations.

\[
NR_h = 40YG_h \\
PR_h = 13.75(6.3206-O_p^{0.5}) + 9YG_h \\
KR_h = 9.4375(14.4914-O_k^{0.5}) + 34YG_h
\]

\[
NR_p = 18YG_p \\
PR_p = 13.75(6.3206-O_p^{0.5}) + .15YG_p \\
KR_p = 9.4375(14.4914-O_k^{0.5}) + 5.1YG_p
\]
Based on crop nutrient requirements and the nutrient content of broiler litter, crop requirements for broiler litter were estimated on a N, P and K basis. For example, application rate on a N basis varies between 1.65 and 3.21 tons of litter per acre depending on soil types. Crop nutrient requirements in terms of broiler litter were estimated based on the nutrient content of broiler litter and different nutrient bases (discussed in model section). Partial enterprise budgets for fescue hay and pasture crops were developed for different yield levels and soil types, average litter application rates, and labor costs. Costs are assumed to be the same for all items except fertilizer, labor and machinery which are directly proportional to yield.

An LP model is developed in which total net return to land and management in the watershed is maximized subject to a set of constraints. The LP model is as follows:

Maximize: \[ Z = \sum_{j=1}^{I} \sum_{j=1}^{J} \sum_{x=1}^{Kx} \sum_{y=1}^{Ly} (P/X_{ijkl} - C_{ijkl})X_{ijkl} - \sum_{j=1}^{I} \sum_{j=1}^{J} \sum_{x=1}^{Kx} P_{j}B_{j}L_{j} - \sum_{m=1}^{3} P_{m}C_{m} \]  

Subject to:
\[ \sum_{j=1}^{J} \sum_{x=1}^{Kx} \sum_{y=1}^{Ly} X_{ijkl} \leq S_{i} \quad \forall \ i \]  
\[ \alpha_{m}B_{ijkl} - \beta_{ijkl}X_{ijkl} \geq 0 \quad \text{where } k = BL \quad \forall \ i, j, l, m \]  
\[ CF_{ijkl} - \beta_{ijkl}X_{ijkl} \geq 0 \quad \text{where } k = CF \quad \forall \ i, j, l, m \]  
\[ \sum_{i=1}^{I} \sum_{j=1}^{J} \sum_{l=1}^{L} B_{ijkl} \leq BL \]  
\[ \sum_{i=1}^{I} \sum_{j=1}^{J} \sum_{l=1}^{L} CF_{ijkl} - CF_{m} = 0 \quad \forall \ m \]
\[ \sum_{i=1}^{I} \sum_{j=1}^{K} \sum_{l=1}^{L} X_{ijkl}^{\text{hay}} = \frac{1}{3} \]
\[ \sum_{i=1}^{I} \sum_{j=1}^{K} \sum_{l=1}^{L} X_{ijkl}^{\text{pasture}} = \frac{1}{3} \]

\[ X_{ijkl}, BL_{ij}, CF_{m} \geq 0 \quad \forall \, i,j,k,l,m \]

where: i has elements of seven soil types; j has elements of fescue hay and pasture; k has elements of commercial fertilizer and litter; l has elements of low, moderately low, moderately high and high yield goals (or associated fertilizer levels); and \( m \) has elements of N, P and K. Variables and parameters are defined as follows: \( X_{ijkl} \) is area of soil i in crop j with fertilizer k at level l and is the decision variable in the LP model; \( BL_{ij} \) is amount of broiler litter associated with each \( X_{ijkl} \); \( CF_{im} \) is amount of \( m \)th commercial fertilizer associated with each \( X_{ijkl} \); \( P_{ij} \) is price of crop j; \( Y_{ijkl} \) is yield of crop j in soil i with fertilizer k at level l; \( C_{ijkl} \) is cost of producing crop j in soil i with fertilizer k at level l, excluding fertilizer cost; \( S_{i} \) is acres in soil i; BL is quantity of broiler litter available; \( P_{BL} \) and \( P_{m} \) are prices of broiler litter and \( m \)th commercial fertilizer, respectively; \( \alpha_{m} \) is amount of \( m \)th nutrient in litter; and \( \beta_{ijkl} \) is the requirements for \( m \)th nutrient in producing crop j in soil i with yield goal l.

Input parameters include: \( P_{ij}, Y_{ijkl}, C_{ijkl}, P_{BL}, P_{m}, S_{i}, \alpha_{m}, \beta_{ijkl}, \) and BL. Crop yields and costs (\( Y_{ijkl} \) and \( C_{ijkl} \)) are differentiated for each \( i,j,k,l \). For each soil, all possible litter uses and associated yield goals are identified, and cost and return budgets for alternative litter uses and crops are developed. Nutrient content of broiler litter is obtained from litter samples. Crop yield responses are established for four yield goals and associated litter application rates. Broiler litter application rates for specific crops
and yields, labor requirements, costs of using litter, and net returns for different litter utilization practices are considered in the enterprise budgets. These budgets are used to develop the coefficients of $X_{iikl}$ in the LP model.

The objective function of the LP model, equation (1), equals the net return to land and management from utilizing litter. Costs of commercial fertilizer and broiler litter are explicitly stated in the objective function. The LP model chooses a crop mix on seven different soils that maximizes net return in the watershed from applying broiler litter or commercial fertilizer to land. Constraint (2) represents the acreage restriction for each soil; namely, the sum of the acreage for activities in a soil should not exceed the area in that soil. Constraints (3) and (4) represent the minimum crop nutrient requirements from broiler litter and commercial fertilizer, respectively. Specific quantities of commercial fertilizer and/or broiler litter are required to achieve each yield goal. The $a_{in}$ parameters are the nutrient contents of N, P and K per unit of broiler litter expressed in commercial fertilizer equivalents. $\beta_{ijm}$ are the nutrient requirements for N, P and K in soil i to grow crop j at fertilizer level l. The minimum crop nutrient requirements are met through either commercial fertilizer and/or litter. Constraint (5) represents the availability of litter. The scenario that all litter generated in the watershed be applied to land in the watershed can be examined by changing the signs from "less than or equal to" to "strictly equal to". Constraints (6) are accounting constraints for total amounts of commercial fertilizer N, P and K. Constraint (7) requires a one to three ratio of hay to pasture acreage. This ratio is based on cow/calf feeding ratios in the area. Constraint (8) ensures that all decision variables are nonnegative.
Results and Analyses

Choice of fertilizer. Four scenarios are analyzed using the LP model. Scenario one assumes that either commercial fertilizer or litter is used to meet crop nutrient requirements but not both. Scenario two assumes that litter application rates are determined on a N basis. Hence, any shortages in P and K that occur after using litter to meet N requirements are made up from commercial fertilizer. Surplus P and K have no value. This assumes farmers do not take credit for excess P and K in litter. In scenarios three and four, litter rates are determined on a P basis and K basis, respectively.

In scenario one, where either litter or commercial fertilizer can be applied, litter is chosen over commercial fertilizer to maximize returns to land and litter management in the watershed. This scenario results in over-application of certain nutrients due to inseparability of nutrients in litter. Since over-application is neither economically efficient nor environmentally sound, the three other scenarios analyze application rates on an N, P or K basis. These scenarios also indicate that litter is chosen over commercial fertilizer. Hence, litter is an inexpensive substitute for commercial fertilizer.

Litter from 6-flock cleanout has higher quality, lower cost, but lower volume than litter from the alternative cleanout schedules (Table 1). To maximize economic returns to land and litter management in the watershed, a 6-flock cleanout schedule should be used because the higher quality and lower cost outweigh the lower volume of litter. Other factors affecting the cleanout decision, such as bird health and quality, are not considered here.
Litter value. A shadow price of broiler litter is estimated for various levels of litter availability. If there is surplus litter in the watershed, then the shadow price is zero. If there is a deficit of litter, then the shadow price is positive. Parametrically changing the quantity of litter available for land application shows that shadow price of litter is a decreasing step function of the quantity of litter. This step function represents the demand for litter. When shadow price is zero, the maximum quantity of litter demanded is determined by total crop nutrient requirements for the watershed.

Using the LP model, estimates are derived for the litter price at which farmers have an incentive to use litter instead of commercial fertilizer, given current market prices for commercial fertilizer. This litter price represents farmers' willingness to pay for litter. Since litter cannot be separated into its nutrient components, the litter values given here are different from those based on nutrient content. Litter would be $33.77-37.22 per ton based on its N, P and K content (25 percent of litter N losses is assumed). Litter value is estimated to be $23.49-35.87 per ton under the N-basis scenario (Table 2). Value estimates for litter given in Table 2 vary due to differences in litter quality (nutrient content) and differences in cleanout costs. Regarding the latter, 3-, 4- and 5-flock cleanout is more expensive on an annual basis than 6-flock cleanout. Only differences in cleanout costs are considered in Table 2. Actual cleanout costs do not affect the value of broiler litter because they represent a cost of broiler production. When these cleanout cost differences are considered, 3-, 4- and 5-flock litter is less valuable than 6-flock litter.

Effects of litter price on litter use. At the current market price of litter in Shoal Creek watershed, $10.83 per ton, all the broiler litter available in the watershed would
be applied to land because this price is below the price of commercial fertilizer. As the price of litter increases, the price advantage of litter relative to commercial fertilizer decreases. Farmers would use all the litter generated in the watershed as fertilizer when they take full credit for the N value of litter because the estimated shadow price of litter is positive. If the price of litter increases from $10.83 to $23.49 per ton for 3-flock litter (or $31.25 for 6 flock litter), farmers would be indifferent between using litter and commercial fertilizer. When litter price is above this threshold level, commercial fertilizer is less expensive than litter and there is no incentive to use litter. As long as broiler litter price does not exceed the threshold price, all litter would be applied to land in the watershed.

**Effects of growth in broiler production.** As broiler production increases in the watershed, the availability of litter and total returns from litter would increase. Crop nutrient requirements from litter in the watershed are estimated to be two times the amount of nutrients in current litter volume when litter is applied on a P basis, three times on a N basis, and three times on a K basis. Therefore, increases in litter availability would increase total net returns in the watershed. Potential negative water quality effects can be minimized by applying litter based on crop nutrient requirements.

Effects of increased litter availability are now presented. First, more of the land area in the watershed would be utilized for litter application. Second, as litter availability increases, the value of litter as measured by its shadow price decreases. Shadow price decreases rapidly at high levels of litter availability indicating that the incentive for farmers to use commercial fertilizer will increase as broiler litter availability increases. Of course, if commercial fertilizer prices decrease, an unlikely
event, then farmers would have less incentive to apply litter. Third, net returns to farmers in the watershed would increase by using this valuable resource to meet crop nutrient requirements in the watershed, but at a decreasing rate as shown in Figures 1, 2 and 3. In these figures, net returns are standardized such that net returns are zero when there is no broiler litter.

Land requirements based on P content of broiler litter are different from those based on N or K. Land area required for litter application is the highest on a P basis and similar on an N or K basis. However, net economic returns are highest on a P basis. Required land area is greatest on a P basis because litter is relatively rich in P and hay and pasture do not require much P. Net return differences among the various scenarios are due to differences in commercial fertilizer prices. In the absence of water quality considerations, applying litter to land based on its P content provides the greatest net returns but requires more land area for spreading litter than when applying litter based on N or K.

Summary and Concluding Remarks

An economic optimization model is developed which determines the economic value of broiler when used to fertilize hay and pasture crops. The model maximizes total net returns to land and litter management in a watershed. Data on soil types, crop nutrient requirements, nutrient content of broiler litter, enterprise budgets, and results from a GIS are integrated into an LP model that determines the optimal rates of litter application to different types of land given the nutrient composition of litter and the profitability of alternative litter management practices. The integrated model is used
to evaluate the potential economic impacts of: increasing the availability of broiler litter; applying litter on different nutrient bases; and using different litter cleanout schedules.

Litter is an inexpensive substitute for commercial fertilizer. Six-flock cleanout schedule is preferred to other cleanout schedules. Litter value varies with nutrient basis, cleanout schedule and availability. Results indicate that these factors, as well as land available for litter application and water quality effects should be considered when determining litter application rates.

In areas having high litter concentration such as Shoal Creek watershed, land application of litter is less likely to cause water quality problems if it is properly managed and applied based on crop nutrient requirements. Nutrients in litter would quickly reach crop nutrient requirements in the watershed when broiler production grows rapidly. The presence of dairy and beef cattle in the area aggravates the water quality problem and requires additional land for cattle manure application. Future studies should analyze the joint effects of cattle manure and broiler litter.

While additional litter would increase total net returns to land and litter management, farmers would have little incentive to use litter if it is more costly. Farm-level models can be used to analyze farmers' choice of optimal litter utilization and management. Information on different farm types in the watershed would be useful in conducting such an analysis.

Other important considerations that could be incorporated in the LP model or used to modify the LP model include: timing of broiler house cleanout (spring and fall), litter storage, time of application; water quality impacts of cattle manure; feeding litter
to cattle; exporting litter outside the watershed; leaching of excess nutrients through
the root zone; risk tolerance levels for water pollutants; and accounting for variability
in the nutrient content of litter.

Since this analysis determines litter application rates based on crop nutrient
needs, the risk of water contamination is expected to be low. However, by
incorporating results from process models which simulate water quality effects in the
LP model, the potential risk of water contamination can be assessed quantitatively.
References


Figure 1. Net returns to farmers by cleanout schedule and litter availability, N basis

$X = \text{litter currently available in the watershed}$
Figure 2. Net returns to farmers by cleanout schedule and litter availability, P basis.

$L = \text{litter currently available in the watershed}$
Figure 3. Net returns to farmers
by cleanout schedule and litter availability, K basis

$ X = \text{litter currently available in the watershed}
Table 1. Cost for cleanout of broiler houses

<table>
<thead>
<tr>
<th>Cost Item</th>
<th>Cleanout frequency every</th>
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<tbody>
<tr>
<td></td>
<td>3-flocks 4-flocks 5-flocks 6-flocks</td>
</tr>
<tr>
<td>Litter per cleanout (tons)</td>
<td>77.36</td>
</tr>
<tr>
<td>Litter per house annually (tons)</td>
<td>141.83</td>
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<tr>
<td>Variable cost (@ $5/ton)</td>
<td>386.80</td>
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<tr>
<td>Total cost: fixed cost ($545.00) + var cost</td>
<td>931.80</td>
</tr>
<tr>
<td>Cleanout cost ($/ton)</td>
<td>12.04</td>
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<tr>
<td>Cost above base (base = 6 flock)</td>
<td>2.46</td>
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<tr>
<td>Total annual cost ($)</td>
<td>1707.63</td>
</tr>
<tr>
<td>N: after 25% loss (lb/ton)</td>
<td>43.39</td>
</tr>
<tr>
<td>P₂O₅ (lb/ton)</td>
<td>82.14</td>
</tr>
<tr>
<td>K₂O (lb/ton)</td>
<td>39.19</td>
</tr>
<tr>
<td>Value of litter based on nutrients ($/ton)</td>
<td>33.77</td>
</tr>
</tbody>
</table>
Table 2. Estimated value of broiler litter by nutrient basis, cleanout schedule and consideration of cleanout cost, dollars per ton

<table>
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<tr>
<th>Cleanout schedule</th>
<th>No consideration of cleanout cost</th>
<th>Consideration of cleanout cost</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N-basis</td>
<td>P-basis</td>
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<tr>
<td>3-flock</td>
<td>23.49</td>
<td>36.22</td>
</tr>
<tr>
<td>4-flock</td>
<td>29.00</td>
<td>38.80</td>
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<td>5-flock</td>
<td>33.14</td>
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<tr>
<td>6-flock</td>
<td>35.87</td>
<td>42.66</td>
</tr>
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Footnotes

1. Respectively, Professor, Research Assistant Professor and Graduate Assistant, Department of Agricultural Economics, University of Missouri-Columbia. Authors thank J.R. Brown and D.D. Buchholz for their assistance in estimating crop nutrient requirements. A version of this paper was presented at the 47th annual meeting of Soil and Water Conservation Society, August 9-12, 1992, Baltimore, Maryland.

2. The seven soil types in the watershed are Scholten Gravelly Silt Loam, Tonti-Scholten Complex, Secesh Silt Loam, Waben-Cedargap Very Gravelly Silt Loam, Tonti Silt Loam, Noark Very Gravelly Silt Loam, and Dunning Silt Loam and Overwashed.

3. The four yield goals are low, moderately low, moderately high and high. Moderately high goals were taken from the soil survey. The other goals were obtained by having agronomists and local extension specialists adjust the moderately high goals to obtain other three yield goals. For example, fescue hay yield goals are 1.5, 2, 2.5, 3 tons per acre on Scholten Gravelly Silt Loam soil for the four yield goals, respectively.