Optimal Farm-Level Use and Value of Broiler Litter

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Abstract

An optimization model is used to determine optimal choice of fertilizer and litter cleanout schedule, to estimate the value of broiler litter, and to evaluate the potential economic effects of land application rates based on different nutrient requirements for a representative broiler farm in Missouri. Results indicate that litter is an inexpensive substitute for commercial fertilizer. Since the model determines litter application rates based on crop nutrient needs, the risk of water contamination would be minimal.

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Introduction

As broiler production becomes more concentrated, the amount of litter disposed in a given area increases. Broiler litter application to land is a major use of broiler litter. More broiler litter is generated than can be utilized in many concentrated production regions in the United States. Increasing concern about surface and ground water quality has focused attention on litter management in areas that have high litter concentration. 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. Litter utilization must balance farm profit and water quality protection. Production options that consider both profitability and water quality have been studied (7).

This study analyzes economic factors affecting litter utilization decisions at the farm level. Emphasis is placed on analyzing the value of litter and grower's decision on litter utilization. Enterprise budgets for crops based on different fertilizer sources, broiler litter cleanout schedules, and litter management practices are used in an optimization model to determine litter application areas and rates that maximize the net return to litter and land management for a representative broiler farm. Contamination can occur when litter applied to land exceeds plant nutrient needs (11). Water quality protection is considered in this study by basing litter application rates on soil type and crop requirements for nutrients. Economic profitability is approached by maximizing net returns to litter and land management.

Procedures and Methods

A representative broiler grower is constructed for the Shoal Creek watershed, located in Barry county, Missouri. This watershed has a total area of 17,232 hectares (42,564 acres). Land in grass and pasture accounts for more than 80 percent of the watershed. Litter is applied to land in hay and pasture either for convenience or for its nutrient value. Broiler, cattle (cow-calf) and dairy are the major livestock activities. The karst features of soils in the area make it vulnerable to water contamination from broiler litter. There are 513 individual land owners in the watershed, of which 48 are broiler growers with 125 broiler houses. While forages are generally less susceptible to runoff and leaching than cultivated crops, the karst topography and high litter concentration increase the likelihood that surface contaminants will reach groundwater. An ARC/INFO Geographic Information System (GIS) is used to store and analyze data on watershed boundaries, land use, soil type, farm size, location and number of broiler houses, and other relevant information.

Based on GIS information and other data sources, the representative broiler farm is constructed to have the following characteristics. The farm has three houses on 41 hectares (102.4 acres). Each house has an area of 149 square meters (16,000 square feet) with a capacity of approximately 20,000 birds. Available area for forage production is 35 hectares (85.51 acres) (79.6 percent of total land in watershed is forage). The prevalent soil type in the watershed, Scholten Gravelly Silt Loam, is assumed to be on the farm.

A litter management practice (LMP) refers to the rate of litter application, litter cleanout frequency and litter selling. Litter cleanout is the removal of accumulated broiler manure and litter from the house. Frequency of litter cleanout varies from every three flocks to every six flocks. About 85 percent of broiler growers clean out every 6-7 flocks or about once a year in the four south-central states of Missouri, Arkansas, Texas and Oklahoma and 92 percent of litter is applied to the land (3). Cleanout is usually contracted out to custom operators. Broilers are marketed at an age of 6-8 weeks. The choice of LMPs affects farm profitability. Since forage producers are assumed to maximize profits, low cost nutrients are required.

Information on nutrient content of broiler litter in Shoal Creek watershed was obtained from a study which sampled and analyzed litter from nine broiler houses in Barry county (9). Compared to Alabama (5) and Virginia (2), Missouri litter has a higher phosphate content, but a similar nitrogen and potassium content. Data show that both quantities and nitrogen (N) content of litter vary with cleanout frequency. Phosphate (P) and potash (K) content do not vary significantly with cleanout frequency (Table 1). N is the primary nutrient of interest in terms of fertility and water quality. Excess N can cause ammonia toxicity in fish and nitrate contamination in drinking water (5).

Crop nutrient requirements for N, P and K were estimated for fescue hay and pasture for each of four yield goals: low, moderately low, moderately high and high. These requirements can be supplied by either commercial fertilizer or broiler litter. Detailed procedures for estimating crop nutrient requirements are provided in Buchholz and Appendix A. 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.

Enterprise budgets were constructed for hay and pasture at the four yield goals. Production costs are assumed to be the same for all items except fertilizer, labor and machinery which are directly related to yield. Budgets were developed for fescue hay and pasture using cost and return data from the Missouri Farm Planning Handbook (4).

The optimization model is as follows:

$$(1)\ \text{Maximize: } Z = \sum_{j=1}^{J} (P_j Y_{ijk} - C_{ijk}) X_{ijk} - \sum_{m=1}^{M} P_m (CF_m + SHTCF_m) + PBL \times BLSELL$$

$$(2)\ \text{Subject to: } \sum_{j=1}^{J} \sum_{k=1}^{K} \sum_{l=1}^{L} X_{jkl} \le SIZE$$

$$(3)\qquad \alpha_m BL_{jl} - \beta_{jlm} X_{jk=BL1} + SHTCF_{jlm} - WSTBL_{jlm} = 0 \quad \forall \quad j,l,m$$

$$(4)\qquad CF_{jlm} - \beta_{jlm} X_{jk=CF1} \ge 0 \quad \forall \quad j,l,m$$

$$(5)\qquad BLSELL + \sum_{j=1}^{J} \sum_{l=1}^{L} BL_{jl} \le BL$$

$$(6)\qquad - CF_m + \sum_{j=1}^{J} \sum_{l=1}^{L} CF_{jlm} = 0 \quad \forall \quad m$$

$$(7)\qquad - SHTCF_m + \sum_{j=1}^{J} \sum_{l=1}^{L} SHTCF_{jlm} = 0 \quad \forall \quad m$$

$$(8)\qquad \sum_{k=1}^{K} \sum_{l=1}^{L} X_{j='hay'kl} \Big/ \sum_{k=1}^{K} \sum_{l=1}^{L} X_{j='pasture'kl} = \frac{1}{3}$$

$$(9)\qquad X_{jkl}, CF_m, SHTCF_m \ge 0 \quad \forall \quad j,k,l,m$$

Variables and parameters in the model are defined according to subscripts such that: crop j has elements for fescue hay and pasture; fertilizer source k has elements for commercial fertilizer and litter for different cleanout schedules; yield goal (and therefore fertilizer level) l has four elements: low, moderately low, moderately high and high; and nutrient m has elements of N, P and K. Therefore, X_{jkl} is area in crop j with fertilizer k at level l, which is the decision variable to be determined by the optimization model. BL_{jl} is amount of broiler litter associated with each X_{jkl}, and CF_{jlm} is the amount of m^{th} nutrient of commercial fertilizer associated with X_{jkl}. C_{jkl} is the cost of producing crop j with fertilizer k at level l, excluding fertilizer cost. SIZE is the number of acres on the farm that is suitable for forage production. BL is quantity of broiler litter available. Y_{jkl} is yield of crop j with fertilizer k at level l. P_j, PBL and P_m are prices of crop j, broiler litter, and m^{th} nutrient, respectively. β_m is the amount of m^{th} nutrient in litter. β_{jlm} is crop j's requirements for m^{th} nutrient with yield goal l. $SHTCF_{jlm}$ is the amount of m^{th} nutrient of commercial fertilizer that is used to supplement for crop j's nutrient requirement at yield goal l after litter application rate is determined on a particular nutrient basis. $WSTBL_{jlm}$ is the amount of m^{th} nutrient of litter that exceeds crop j's nutrient requirement at yield goal l after litter application rate is determined on a particular nutrient basis. Input parameters include P_j, Y_{jkl}, C_{jkl}, PBL, P_m, SIZE, β_m, β_{jlm}, and BL. Crop yields and costs (Y_{jkl} and C_{jkl}) are differentiated for each j, k, l.

As presented in the LP model, the representative farm efficiently utilizes the annual litter load for that farm. The objective function of the LP model (1) is 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 that maximizes net return from applying broiler litter or commercial fertilizer to land. Constraint (2) represents the acreage restriction; namely, the sum of the acreage for forage activities should not exceed the area available for forage. Constraints (3) and (4) represent the crop nutrient requirements based on broiler litter and commercial fertilizer, respectively. Specific quantities of commercial fertilizer and/or broiler litter are required to achieve particular yield goals. Parameters β_m is the quantity of the m^{th} nutrient per unit of broiler litter expressed in commercial fertilizer equivalents. β_{jlm} is the crop requirement for the m^{th} nutrient by crop j for yield goal l (or at fertilizer level l). Crop nutrient requirements are met using either commercial fertilizer and/or litter. Three scenarios are considered: N-basis, P-basis and K-basis.

In the N-basis scenario, litter application rates are estimated based on crop N requirement and N content of litter. Any shortages in P and K ($SHTCF_p$ and $SHTCF_k$) after using litter to meet N requirements are made up from commercial fertilizer. No credit is given for excess P and K in litter ($WSTBL_p$ and $WSTBL_k$). Scenarios for applying litter on a P or K basis are also analyzed. The assumption that excess nutrients are freely disposed is practical from the perspective of farm management. Constraint (5) represents the availability of litter. Constraints (6) and (7) are the accounting constraints for the m^{th} commercial fertilizer and supplemental commercial fertilizer, respectively. Constraint (8) restricts the ratio of hay to pasture to 1:3. This ratio conforms with the cow/calf feeding ratio in the Missouri Farm Planning Handbook. Constraint (9) ensures that decision variables are nonnegative.

Variations of the LP model are used to evaluate several litter utilization scenarios. For example, the sensitivity of litter use to changes in market price of litter and litter availability are evaluated. Effects of changes in litter prices on utilization and net farm returns were examined by parametrically changing litter price in the LP model. This analysis is particularly relevant because farmers face different litter prices. Changes in net farm returns are examined for different optimal litter utilization alternatives.

A broiler grower decides whether to spread litter on his/her land and/or to sell it, the yield goal for hay and pasture, and the cleanout schedule. Even though the cleanout schedule is primarily determined by the broiler production plan, growers tend to clean out houses less frequently due to the high cost of cleanout. However, when the fertilizer value of litter is considered, it may be profitable for growers to change their cleanout schedule. Broiler integrators can provide growers with a financial incentive to do more frequent cleanout in order to enhance the quality of broilers. For example, some integrators are willing to pay growers $60 for each cleanout. The effects of this incentive are analyzed using the optimization model.

Variations of the LP model also include different cleanout schedules. Nutrient content and cleanout cost vary with cleanout schedule (Table 1). In this study, only cost differences were considered because cleanout is a necessary activity in broiler production.

Results and Analysis

Litter Utilization

A profit-maximizing grower would use litter to produce forage on his/her land because is an inexpensive substitute for commercial fertilizer. Excess litter is sold to other farmers. Litter should be applied on an N basis because net returns are higher than on a P or K basis (Table 2). The grower should choose a 6-flock cleanout schedule because it provides the highest net returns.

About 327 tons of litter are generated annually by a three-house farm using a 6-flock cleanout schedule. For this farm, 125 tons (or 38 percent) are applied to the grower's 41 hectares of land because the value of litter is higher than the market price. The remaining 202 tons (or 62 percent) of surplus litter are sold to other farmers. Current market price for litter is $10.83 per ton. As litter price increases, the price advantage of litter relative to commercial fertilizer decreases.

As number of houses per farm and litter availability increases, additional income is earned provided the additional litter can be sold. As commercial fertilizer prices decrease, the incentive to apply litter to land decreases.

Land requirements for the three nutrient scenarios are different. Land area required to apply the available litter (327 tons) is higher on a P basis (180 hectares or 444 acres) than on an N or K basis (90 hectares or 223 acres). Land area is greatest for the P scenario because litter is relatively rich in P and hay and pasture do not require much P. Economic return is higher on an N basis than on a P or K basis. Net returns for the three scenarios vary due to differences in the price of each commercial fertilizer nutrient. Applying litter to land based on its N content should reduce nitrate runoff and nitrite concentrations in groundwater. However, excess P may contribute to pollution of streams and lakes receiving runoff from land applied litter.

Litter Value

Per unit value of surplus litter equals the market price. To estimate the value of litter in forage production, a forage producer is modeled by dropping irrelevant litter activities and constraints from the optimization model. A forage producer can buy litter or commercial fertilizer but would prefer litter to commercial fertilizer because of its lower price. The optimal amount of litter to purchase is estimated. Shadow price is used to measure contribution of additional unit of litter to farm profit when at the optimal use of litter, holding others constant (assuming no sale activity). Under current market conditions, the shadow price of litter is estimated to be $21.12, $23.41, $25.22 and $27.54 per ton of litter for 3-, 4-, 5-, and 6- flock cleanout on an N basis, respectively (Table 3). Since the current market price for litter is below the shadow prices, forage producers have an incentive to use litter. Shadow prices of litter are higher when application rate is determined based on P. However, the total net return to litter when applied on a P basis is lower than when applied on an N or K basis because considerable N and K must be added to meet crop requirements. Litter value ranges from $33.77 to $37.22 per ton if the N, P and K in litter are valued at current market prices. Since litter cannot be separated into its nutrient components, these litter values exceed the shadow prices which range from $21.12 to 27.54 per ton.

If the price of litter increases from its market price of $10.83 to its maximum N-basis shadow price of $27.54 per ton, farmers would be indifferent between using litter (from 6-flock cleanout) and commercial fertilizer. For market prices above this level, commercial fertilizer becomes less expensive than litter. As long as market price for broiler litter does not exceed $27.54 per ton, litter will be used in forage production. When market price of litter exceeds this upper limit, there is no incentive to use broiler litter in forage production.

When broiler growers view litter as a waste product rather than a valuable resource in forage production, they tend to minimize litter handling costs rather than maximize returns to litter. Hence, over-application of litter to land is likely in the absence of guidelines for litter disposal. The likelihood of over-application of litter is reduced when litter is applied to meet forage requirements for nutrients.

Effect of cleanout compensation

Cost and return information suggest that growers will choose a 6-flock cleanout. When growers receive $60 per cleanout from integrators, they would switch to 4-flock cleanout with little change in net return. Hence, cleanout will occur more often when growers are compensated.

Litter quality varies with cleanout schedule. Ranking of litter quality by cleanout frequency is 6-flock, 5-flock, 4-flock and 3-flock cleanout. Litter application results in economic benefits because litter has a high nutrient content, making it an excellent fertilizer. To balance these benefits against the potential negative impacts on water quality, litter should be applied to land at a rate that does not exceed crop nutrient requirements.

Summary and Conclusions

This paper examines optimal utilization of broiler litter at the farm level in Missouri's Shoal Creek watershed. Litter is a valuable resource whose rich nutrients and low cost make it an excellent substitute for commercial fertilizer in crop production. Litter is also a potential water pollutant. Such pollution can be reduced and hopefully minimized by basing litter application rates on crop nutrient requirements.

Litter is a by-product of broiler production. Broiler growers typically have excess litter. Small farms with many houses have a large quantity of excess litter which can be sold. Over-application of litter to land is likely to occur when buyers cannot be found or high transportation costs make shipping to other areas prohibitive.

A farm-level optimization model was used to analyze a broiler grower's choice of litter utilization and management practices. The model maximizes net returns to land and litter management and was used to estimate the fertilizer value of litter. Crop enterprise budgets were constructed that consider broiler litter application rate for each yield goal, labor costs, and net returns (returns minus costs) for fescue hay and pasture. Data on soil types, crop nutrient requirements, nutrient content of broiler litter, enterprise budgets, and results from a GIS were integrated with the optimization model. The integrated model was used to evaluate changes in net farm returns from increased availability of broiler litter as well as economic incentives for increasing the frequency of litter cleanout. Total net returns and litter value varied, being higher on an N basis than on a P or K basis. Shadow prices were $21.58, $27.54 and $36.89 per ton based on K, N and P, respectively, for a 6-flock cleanout frequency.

Other important factors that can 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 to other areas; leaching of nutrients through the root zone; risk tolerance levels for water pollutants; and accounting for variability in the nutrient content of litter.

Since no process model that is specific for broiler application and adequately handles litter on pasture was available at the time of this analysis,[3] the risk of groundwater contamination from use of broiler litter can not be demonstrated. As a result, nutrient leachate and/or runoff cannot be incorporated explicitly in the optimization model. A rule of thumb for water quality protection is to determine the litter application rate needed to meet crop nutrient requirements. While zero water contamination cannot be guaranteed, the risk of water contamination would be minimal.

[3]Authors have now obtained a process model POULTN, which was developed by Don Scott from the University of Arkansas. This model simulates the decomposition and transport of nitrogen from field application of poultry litter and computes runoff, volatilization, leaching and other parameters.

Table 1. Cost for cleanout of broiler houses and nutrient content for various cleanout frequencies

Item	3-flock	4-flock	5-flock	6-flock
Litter per cleanout (tons)	77.36	91.20	105.12	118.96
Litter per house annually (tons)	141.83	125.40	115.63	109.05
Variable cost @ $35/ton	386.80	456.00	525.60	594.80
Total cost = fixed cost ($545) + variable cost	931.80	1001.00	1070.60	1139.80
Cleanout cost w/o $60 compensation	12.04	10.98	10.18	9.58
Cost above base (base = 6 flock w/o compensation)	2.46	1.40	0.60	0.00
Cleanout cost w/ $60 compensation	11.27	10.32	9.61	9.08
Cost above base (base = 6 flock w/o compensation)	1.69	0.74	0.03	-0.50
Total annual cost w/o compensation ($)	1707.63	1376.89	1177.11	1044.70
Total annual cost with $60 compensation	1598.42	1294.13	1111.20	990.17
N after 25% loss (lbs/ton)	43.39	49.40	54.39	59.39
P2O5 (lbs/ton)	82.14	82.14	82.14	82.14
K2O (lbs/ton)	39.19	39.19	39.19	39.19
Value of litter based on nutrients ($/ton)	33.77	34.92	36.07	37.22

Table 2. Annual net farm return for different nutrient scenarios, with and without compensation for litter cleanout

Cleanout schedule	Net return ($)					
	w/o compensation			with compensation		
	N-basis	P-basis	K-basis	N-basis	P-basis	K-basis
3-flock	13,260	13,020	13,252	13,587	13,348	13,580
4-flock	13,397	13,079	13,311	13,646	13,327	13,559
5-flock	13,523	13,152	13,384	13,721	13,349	13,582
6-flock	13,621	13,218	13,451	13,784	13,382	13,615

Table 3. Shadow prices for litter in forage production on an N, P and K basis for different cleanout schedules

Cleanout schedule	Shadow price ($/ton)		
	N-basis	P-basis	K-basis
3-flock	21.12	33.44	21.58
4-flock	23.41	34.59	21.58
5-flock	25.22	35.74	21.58
6-flock	27.54	36.89	21.58

Appendix A. Estimating Fescue Hay and Pasture Requirement for Nutrients

Nitrogen requirements are estimated as NR = ßYG for fescue hay and pasture where: NR is total nitrogen requirement (lbs/ac), ß is pounds of nitrogen per unit of yield, and YG is yield goal (ton/ac for fescue hay and aum/ac for fescue pasture), and ß = (40 18)' for hay and pasture, respectively.

Phosphate requirements are estimated as $PR = (110/t)*(DP^{.5}-OP^{.5}) + øYG$, where PR is total phosphate requirement (lbs/ac); t is number of years to increase soil test to desired level (t=8); DP is desired level (lbs) = 40; OP is the observed level (lbs); ø is phosphate removal (lbs/ac). Estimation equations are:

$PR = 13.75(40^{.5}-OP^{.5}) + 9YG$ for fescue hay, and

$PR = 13.75(40^{.5}-OP^{.5}) + .15YG$ for fescue pasture.

Potassium requirements are estimated as $KR = (75.5/t)*(DK^{.5}-OK^{.5}) + cYG$, where KR = total potassium requirement (lbs/ac); t is number of years to increase soil test to desired level (t=8); DK is the desired level (lbs); OK is the observed level (lbs); c is potassium removal (lbs/ac). Estimation equations are:

$KR = 9.4375(DK^{.5}-OK^{.5}) + 34YG$ for fescue hay, and

$KR = 9.4375(DK^{.5}-OK^{.5}) + 5.1YG$ for fescue pasture,

where $D_k = 160+5(CEC)$ and CEC is a measure for cation exchange capacity. Soil parameters for Scholten soil used to estimate nutrient requirements are: organic matter = 1.8%, pH = 5.0, OP = 5, OK = 160 and CEC = 10.

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