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PHOSPHORUS-BASED MANAGEMENT OF BROILER LITTER AS AGRICULTURAL FERTILIZER

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ABSTRACT

We calculated the profitability of using broiler litter as a source of plant nutrients using the phosphorus consistent litter application rule. The cost saving by using litter is 37% over the use of chemical fertilizer alone to meet the nutrient needs of major crops grown in Alabama. In the optimal solution, only a few routes of all the possible routes developed were used for inter- and intra-county litter hauling. If litter is not adopted as the sole source of crop nutrients, the best environmental policy may be to pair the phosphorus consistent rule with taxes, marketable permits, and subsidies.

Excessive manure production and lack of its proper disposal have been a serious concern in regions where industrialized productions of livestock and poultry dominate the agricultural sector [1]. This is no where more evident than in the southeastern states of the United States (for example, Alabama, Arkansas, Georgia, Mississippi, as well as West Virginia and Maryland) where broiler industry contributes significantly to the agricultural revenue as well as litter production. High nutrient content, especially nitrogen, phosphorus, and potassium in broiler litter can make it a cheap substitute for chemical fertilizers in crop production. Therefore, if applied properly, it can enhance profit potential for both broiler producers from the sale of broiler litter and for crop producers by using broiler litter as nutrient sources in crop production. If applied improperly, phosphorus build-ups in soil and phosphorus runoff from crop field to nearby waterbodies would be a common occurrence. Evidence of phosphorus pollution problems such as eutrophication of waterbodies from broiler litter application is quite prevalent in watersheds in the region [2]. Although best management practices (BMPs) have been initiated by the Natural Resource Conservation Service for proper disposal of litter, broiler litter application in crop production continues to be a concern where nonpoint sources of pollution are a common problem.

Our purpose is to assess the economic feasibility of transporting broiler litter from surplus broiler litter production counties to other counties where litter can be applied in crop production in an environmentally acceptable way. We propose to do this by using a "phosphorus consistent" rule. We define the phosphorus consistent rule as the application of litter based on the Cooperative Extension Service's phosphorus recommendation rate for a given crop in a given region. We chose the rule in assessing this problem because phosphorus remains a primary element of concern from the aspect of surface water quality. It is also considered a limiting nutrient for eutrophication in fresh water. Moreover, broiler litter contains a high concentration of water-soluble phosphorus (often more than 0.02% of the weight), making it susceptible to runoff. Several studies in the past considered nitrogen management as major concerns in agriculture [3-5]. However, in concentrated animal production areas, many researchers have shown the need to address a phosphorus pollution problem [6-11].[1] Broiler litter can be applied in crop production with less information when the phosphorus consistent rule is used. This contrast greatly with Jones and D'Souza's method [12] which although effective, requires a lot of information to formulate a litter application rule. Therefore, our model may be parsimonious when comes to developing an effective model to address phosphorus eutrophication problems in watersheds where broiler litter application is common.

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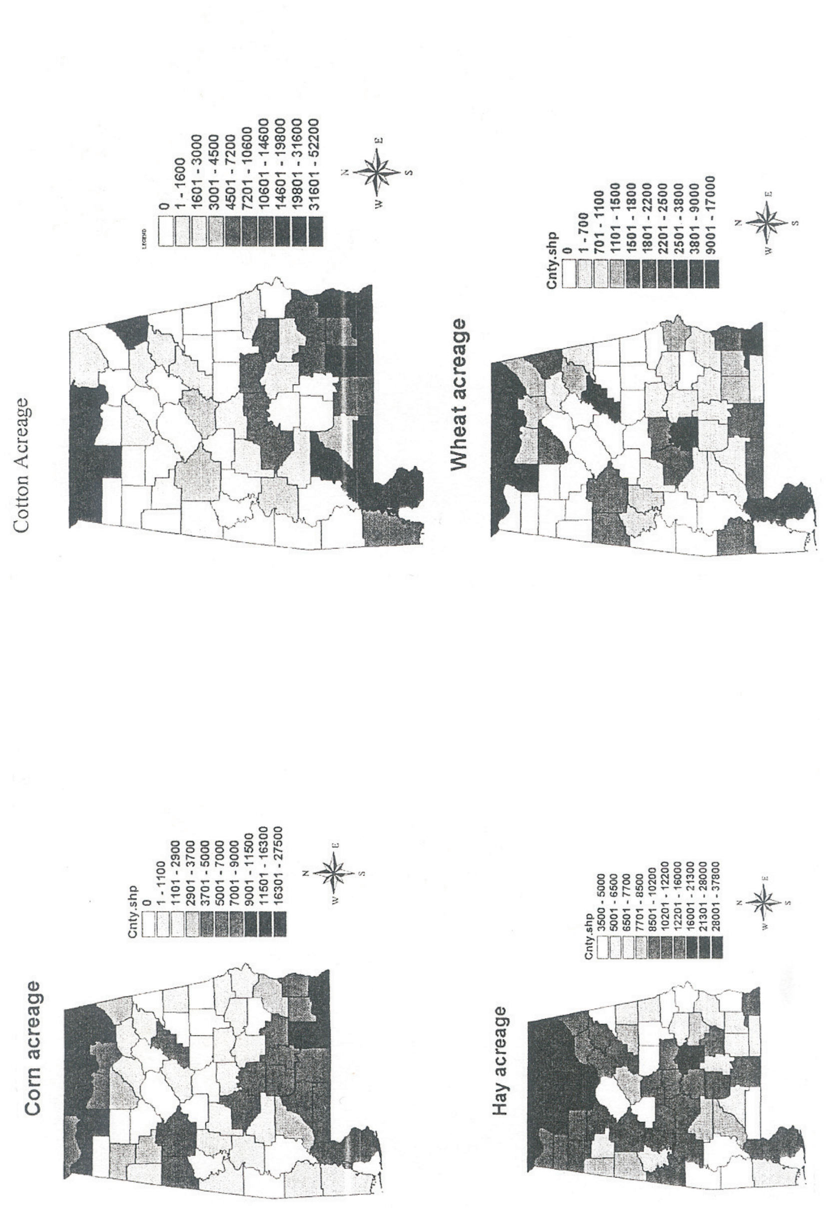
[1] Phosphorus excretion is the best way to define Concentrated Animal Feeding Operations. Phosphorus is linked directly to surface water impairment, so it is a good gauge of the potential environmental impact of an animal feeding operation. And unlike nitrogen which can take a number of different forms, phosphorus is non-volatile. Phosphorus is, as a result, a more reliable and a more easily measured indicator of environmental risk. Using phosphorus excretion to define CAFO will encourage the owners and operations of animal feeding operation to take steps to reduce nutrient output at the source. Since the focus of the CAFO and AFO should be how to manage manure and waste to protect water quality rather than the type of animal involved, the method outlined in this study would be an acceptable method of overcoming the manure overproduction problem. *Source:* Draft comments on Proposed EPA CAFO rules (North Carolina State University).

We developed a transportation model to find the most cost-efficient routes for litter transfer to meet the total nutrient demands of major crops grown in the region. We calculated the extra cost required above the minimum cost solution when transferring excess litter from the most problematic counties in the region is a priority. We also showed the change in the total litter use and cost when the litter price is varied and when we considered temporal and spatial variations in crop and broiler production. For a demonstration purpose, we used broiler and crop production data from Alabama (Figure 1). This is because Alabama shares similar characteristics of other broiler producing states in the region such as the presence of a dominant broiler production sector, contribution of significant revenue to agricultural income, and existence of severe nonpoint sources of water pollution that is attributed to the broiler industry.

BROILER LITTER AS A CROP NUTRIENT SOURCE

Among the several solutions outlined for the broiler litter problem in the region, its uses as a source of crop nutrients and animal feeds are the major ones. However, broiler litter is not widely accepted as an animal feed leaving its major use as a source of crop nutrients. The average macronutrient composition of broiler litter is 62: 60:40 $N:P_2O_5:K_2O$ pounds per ton [13]. Current estimates of the value of the macronutrient content in broiler litter (macronutrient amounts multiplied by price per unit of macronutrient) is $35.60 per ton. The absence of a well functioning market and imperfect information about the benefits of reasonable long-term application of broiler litter results in current selling prices of approximately $10 per ton in its as-is-form. The price is an exogenous price rather than a nutrient-based content price.

Since all the nutrients from litter are not available to the crop in the year of application, the assumption is that the release rates of organic nitrogen are 50% during the first year, 12% in the second year, 5% in the third year, and 2% each in the fourth and the fifth year. It was also assumed that litter contains 0.9% organic nitrogen and 2% inorganic nitrogen. Additional assumptions were that only 80% of inorganic N, 71% of organic N, 75% of phosphorus and 75% of potassium are available to the plant [14]. The chemical fertilizer cost used in calculation was obtained from the Alabama Cooperative Extension System (ACES). According to the ACES report, the prices of custom applied $N:P_2O_5:K_2O$ in the region were 0.30, 0.28, and 0.16 dollars per pound, respectively [15]. These prices include the costs for hauling and application. For example, the standard fertilizer recommendation for cotton and corn in North Alabama for soils with a "medium" phosphorus and potassium levels is 60:40:40 and 120:40:40 pounds $N:P_2O_5:K_2O$, respectively [16]. Using 1999 prices, the use of recommended level of chemical fertilizer cost $35.60 and $53.60 per acre for cotton and corn, respectively. Given the assumption of the nutrient content in broiler litter and prevailing rates of


Cotton Acreage
LEGEND
0
1 - 1600
1601 - 3000
3001 - 4500
4501 - 7200
7201 - 10600
10601 - 14600
14601 - 19800
19801 - 31600
31601 - 52200
N
W
E
S
Wheat acreage
Cnty.shp
0
1 - 700
701 - 1100
1101 - 1500
1501 - 1800
1801 - 2200
2201 - 2500
2501 - 3800
3801 - 9000
9001 - 17000
N
W
E
S
Corn acreage
Cnty.shp
0
1 - 1100
1101 - 2900
2901 - 3700
3701 - 5000
5001 - 7000
7001 - 9000
9001 - 11500
11501 - 16300
16301 - 27500
N
W
E
S
Hay acreage
Cnty.shp
3500 - 5000
5001 - 6500
6501 - 7700
7701 - 8500
8501 - 10200
10201 - 12200
12201 - 16000
16001 - 21300
21301 - 28000
28001 - 37800
N
W
E
S

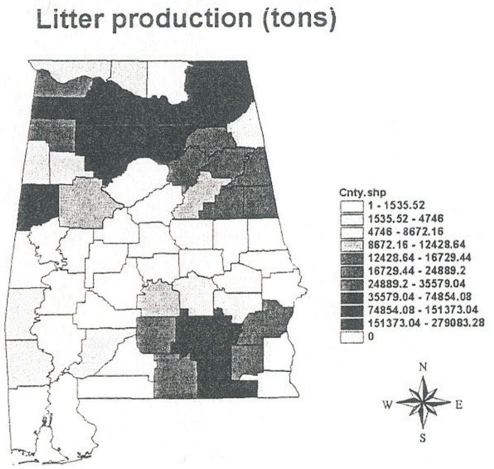


Figure 1. Crop acreage (corn, cotton, hay, and wheat) and litter production (tons) in Alabama.
Source: Alabama Agricultural Statistics Service, 1998.

loading ($0.50 per ton), hauling ($0.10 per ton per mile), and spreading ($3.50 per acre) costs, the use of broiler litter at the recommended rate satisfies the phosphorus requirement at a cost saving of $18.52 per acre over the chemical fertilizer. This suggests that litter can be economically transported within 164 miles from the production facilities. This constraint on distance accommodates an economic transfer of litter from concentrated litter production counties to the major crop production counties. Table 1 identifies breakeven distances for the economical utilization of litter in the production of corn and cotton in the Northern Alabama region based on the stated assumptions. Because of the carry-over effect of nitrogen from year one through year five, litter can be transported further if it is applied continuously. For example, in cotton litter can be economically transported 136 miles in the first year but that break-even-distance increases annually up to 164 miles in the fifth year. Therefore, there is a potential that broiler litter can be used to satisfy crop nutrient needs in the region. Considering the water quality concern, it would be informative to know if the nutrient needs of the region can be satisfied at the minimum cost level with broiler litter as a crop nutrient source.

A linear programming model was developed to address the economics and environmental issues related to broiler litter utilization. The model assumed satisfaction of the nutrient needs of all counties in the state. The objective of the model is to reduce the total costs of satisfying nutrient needs in the state without an over application of phosphorus and nitrogen. The model allowed for

Table 1. Economics of Using Broiler Litter as a Substitute for Chemical Fertilizers for Corn and Cotton in North Alabama (Per Acre Basis)

		Total cost of fertilizer	Broiler litter ($)			Savings from broiler litter	Breakeven distance
Crop	Year	($/acre)	*N*	K_2O	Litter	Use ($)	(miles)
Cotton	Year 1	35.60	8.52	2.13	8.90	16.05	135.68
	Year 2	35.60	7.11	2.13	8.90	17.46	152.01
	Year 3	35.60	6.52	2.13	8.90	18.05	158.47
	Year 4	35.60	6.29	2.13	8.90	18.28	161.05
	Year 5	35.60	6.05	2.13	8.90	18.52	163.74
Corn	Year 1	53.60	26.52	2.13	8.90	16.05	135.68
	Year 2	53.60	25.11	2.13	8.90	17.46	152.01
	Year 3	53.60	24.52	2.13	8.90	18.05	158.47
	Year 4	53.60	24.29	2.13	8.90	18.28	161.05
	Year 5	53.60	24.05	2.13	8.90	18.52	163.74

satisfaction of the nutrient needs of the region either by application of chemical fertilizer or litter using the region's constraints on broiler litter production and crop acreages. The phosphorus-consistent rule for litter application was a binding constraint imposed on the four major crops grown in the region; namely, corn, cotton, wheat, and hay. Pastureland was not modeled because most of it already has a high concentration of phosphorus [17].

The objectives of the cost-minimizing optimization model were to:

1. minimize the total expenditure on crop nutrients through the substitution of broiler litter for chemical fertilizer;
2. analyze the economics associated with the substitution of broiler litter for chemical fertilizers;
3. select the most efficient transportation routes for litter transportation; and
4. provide an overview of the economic interdependencies inherent in broiler litter transportation.

MODEL

The following objective function and constraints were programmed into the model to meet the defined objectives:

$$\underset{W,X,Y}{Min\ Z} = \sum_{a=1}^{4} \sum_{k=1}^{67} L_{ak} W_{ak} + \sum_{t=1}^{3} \sum_{a=1}^{4} \sum_{k=1}^{67} P_t X_{tak} + \sum_{i=1}^{I} \sum_{j=I+1}^{67} T D_{ij} Y_{ij} \tag{1}$$

Subject to:

$$\sum_{t=1}^{3} \sum_{a=1}^{4} \sum_{k=1}^{67} R_{tak} F_{tak} - \sum_{t=1}^{3} \sum_{a=1}^{4} \sum_{k=1}^{67} C_{tak} W_{ak} - \sum_{t=1}^{3} \sum_{a=1}^{4} \sum_{k=1}^{67} X_{tak} <= 0 \tag{2}$$

$$\sum_{a=1}^{4} \sum_{k=1}^{67} W_{ak} <= B_k \text{, for all } k = 1, 2, \ldots, 67 \tag{3}$$

$$\sum_{a=1}^{4} \sum_{k=1}^{67} F_{ak} = R \tag{4}$$

Here, L_{ak} is the cost (loading, spreading, and cost of litter) of applying litter on crop acreage a in k county ($ per ton), W_{ak} is the tons of litter applied on crop acreage a in county k, p_t is the price of t chemical nutrient in dollars per pound, T is the cost in dollars of transferring one ton of litter to a distance of one mile, D_{ij} is the distance in miles from surplus county i to the deficit county j, and Y_{ij} is the total tons of litter transported from county i county to j. In the first constraint equation (equation 2),

R_{tak} represents nutrient t requirement for crop acreage a in county k, F_{tak} is crop field where nutrient t is applied to crop acreage a in county k, C_{tak} is t nutrient from litter applied on crop acreage a in county k, W_{ak} is the amount of litter applied on crop acreage a in county k, X_{tak} is the amount of nutrient t applied on crop acreage a in county k from a chemical fertilizer source. The value of t includes 1, 2, and 3 to represent the nitrogen, phosphorus, and potassium respectively in fertilizer. If $t = 2$ in this equation, it indicates a phosphorus equality constraint. In the second constraint equation (equation 3) W_{ak} is the litter applied on crop acreage a in county k, and B_k is the total amount of broiler litter produced in county k. The third constraint (equation 4) states that all the crop land in four crops in each county sum to the total crop land in the four crops in the region (R). There are 67 counties in Alabama hence maximum value of $k = 67$.

The objective function minimizes the total cost of meeting nutrient requirements, Z, in the state which requires minimization of the cost of chemical fertilizer, the cost of broiler litter application, and the cost of transportation. The hauling, loading, and spreading costs are built into the model. The first constraint equation (equation 2) requires that all nutrient requirement needs of the crop in the region be met from either broiler litter or chemical fertilizer. The second constraint equation (equation 3) indicates that the total litter used in surplus and deficit counties cannot exceed the total amount of litter production in the region. We compared the results among three scenarios wherein (i) only the phosphorus equality constraint is imposed, (ii) both nitrogen and phosphorus equality constraints are imposed, and (iii) nitrogen, phosphorus, and potash equality constraints are imposed.

DATA

Data collected from the Census of Agriculture [18] include crop acreage and broiler production in Alabama's 67 counties. The estimated broiler litter production in each county was calculated using the formula provided by the Alabama Cooperative Extension System.[2] Individual crop acreage and broiler production figures for each county show that the five largest broiler-producing counties are Blount, Cullman, DeKalb, Marshall, and Walker. The majority of the counties in the northern part of the state produce broiler litter sufficient to meet the nitrogen, phosphorus, and potash needs of the respective county. For example, the top eight counties considered in this study produced more than 1,000 tons equivalent of phosphorus from broiler litter. The major crop producing counties are Lauderdale, Lawrence, Limestone, and Madison. Since the counties producing the most crops and the most broiler litter are not the same, the litter transportation

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[2] Broiler litter is calculated based on the conversion formula as follow: Total litter amount = Number of broiler*live weight*amounts of litter produced (0.7).

decision is affected mainly by the distance between these counties. Figure 1 and Table 2 show the corn, cotton, hay, wheat, broiler numbers, and approximate amount of litter produced in the state in 1998.

Distances between counties were calculated using the centroid feature available in ARCINFO 8.1 software. Because information on individual farmers is kept confidential by the National Agricultural Statistics Service, we determined the center point of each county and then calculated the distance between the center point of one county and that of another. The unit cost for transportation represents the cost of transferring one ton of broiler litter to a distance of one mile. The cost is considered to be $0.10. The hauling and spreading costs are $3.50 per ton per acre.

RESULTS

The minimum cost solution, the amount and cost of chemical fertilizer used, and the amount of poultry litter and chemical fertilizers used under NPK availability, NPK release, and NPK content scenarios are shown in Tables 3 and 4. Except for the chemical fertilizer only option, we ran the model under three scenarios: only phosphorus, both nitrogen and phosphorus, and all nitrogen, phosphorus, and potash equality constrained.

Using only chemical fertilizer proved to be the most expensive source of meeting the crops' nutrient needs. It would cost $97 million to meet the nutrient needs of Alabama's corn, cotton, hay, and wheat for one year. The total cost did not change with enforcement of different nutrient equality constraints. Whether P_2O_5 only, N and P_2O_5 only, or N, P_2O_5, and K_2O were all constrained, the results were the same since the central planner can buy each macronutrient fertilizer element individually.

We compared the chemical fertilizer only option to the combination of broiler litter and chemical fertilizer option. First, we made the comparison based on the nutrient content in litter (62:60:40 lbs/ton N, P_2O_5, and K_2O). If all the nutrient constraints were set to equality, meaning all the nutrients are applied in an exact amount, the total cost of meeting the nutrient needs for the four crops was 37% less than the cost of meeting the nutrient needs using only chemical fertilizer. Only 0.9% of the litter produced in the state was left unused. When nutrient constraints were set to both nitrogen and phosphorus equality, the cost was slightly lower than when all nutrients are constrained to be equal. In this situation, the hypothetical central planner does not purchase any phosphorus from chemical sources; all of the needed phosphorus comes from poultry litter. Nitrogen purchased from a chemical source also declines compared to all N, P, and K equality constraints. In this case, slightly less than 0.9% of broiler litter produced remains unused. The total cost of chemical fertilizer is also less than when NPK equality constraints are imposed. When only the phosphorus equality constraint is imposed, the solution is similar to the N and P equality constraint solution.

Table 2. Crop and Broiler Production Status in Alabama (1998)

Counties	Acreage Corn	Cotton	Hay	Wheat	Broiler number (000)	Annual litter (tons)
Madison	16300	29900	18500	17000	0	0
Jackson	27500	600	21300	3800	26078	43811
Limestone	13500	52200	20000	15000	3628	3628
Lauderdale	7000	18800	28000	8000	2688	4516
DeKalb	15500	0	32800	1400	89892	151019
Colbert	14000	23300	9200	900	6281	10552
Lawrence	13200	31600	23000	3500	29864	50172
Morgan	6400	0	26300	1500	24702	41499
Marshall	8600	0	22500	1500	62352	104751
Cherokee	3300	17500	9500	1800	5519	9272
Franklin	0	0	14400	0	25991	43665
Cullman	3700	1200	37800	1800	168279	282709
Blount	2100	0	18600	0	58544	98354
Etowah	2300	3000	14000	500	19557	32856
Winston	0	0	10500	0	26115	43873
Marion	3500	0	11100	0	8389	14094
Cleburne	0	0	4400	500	51212	86036
Calhoun	2000	1000	13900	1400	12113	20350
St. Clair	0	0	14200	0	18940	31819
Walker	0	0	12000	0	38092	63995
Lamar	2600	900	8200	0	1442	2423
Fayette	3700	1600	5800	0	1049	1762
Jefferson	0	0	5000	0	229	385
Talladega	9000	3000	10800	3400	8655	14540
Randolph	900	0	7500	0	14044	23594
Clay	0	0	8000	0	16491	27705
Shelby	1100	4400	8500	0	0	0
Tuscaloosa	5000	4500	10200	1600	6191	10401
Pickens	4300	1900	8000	2500	28695	48208
Chambers	0	0	6900	0	0	0
Bibb	0	0	3500	0	0	0
Tallapoosa	0	0	4400	0	1143	1920
Coosa	0	0	3600	0	0	0

Table 2. (Cont'd.)

	Acreage				Broiler number (000)	Annual litter (tons)
Counties	Corn	Cotton	Hay	Wheat		
Chilton	0	1600	9500	0	0	0
Greene	0	0	7700	1400	0	0
Hale	2800	0	10700	1500	765	1285
Lee	500	2400	4100	0	0	0
Sumter	1100	0	11000	0	0	0
Elmore	2200	12800	10400	900	0	0
Perry	2500	2800	9800	1000	0	0
Autauga	2800	10600	9600	2100	0	0
Macon	900	5600	5500	600	0	0
Dallas	4000	14600	13200	1800	0	0
Russell	800	0	4600	1300	0	0
Montgomery	1800	1900	24000	900	3003	5045
Marengo	1900	3600	16000	0	0	0
Lowndes	4100	0	14800	7100	7132	11982
Bullock	0	1100	8000	0	3834	6441
Barbour	3300	7200	6400	900	4329	7273
Choctaw	0	0	4400	0	2129	3577
Wilcox	2900	2600	8000	900	188	316
Pike	6700	11500	12200	600	19043	31992
Crenshaw	5800	0	7200	700	25673	43131
Butler	3900	0	9200	1100	10430	17522
Henry	8100	16200	4000	2100	930	1562
Clarke	0	0	4600	0	0	0
Monroe	3500	28700	8300	500	1502	2523
Dale	6200	8900	5500	1400	13067	21953
Conecuh	4000	3900	6500	700	0	0
Coffee	9800	19800	7700	1300	51212	86036
Washington	2000	0	5000	2200	2561	4302
Convington	4100	14100	9400	2500	20902	35115
Houston	13700	22900	10800	3200	2070	3478
Geneva	11500	25500	7200	1000	31866	53535
Escambia	7400	28200	4600	2500	0	0
Baldwin	6000	16200	10000	9000	0	0
Mobile	2500	12800	7700	0	0	0

Table 3. Optimal Amount of Broiler Litter Used Under Three Scenarios and Three Nutrient Constraint Situations (First Year)

	Constraints								
	Based on nutrient content			Based on nutrient release			Based on nutrient availability		
Items	N, P, and K equality	N and P equality	P equality	N and P equality	N, P, and K equality	P equality	N, P, and K equality	N and P equality	P equality
Total cost (dollars)	61,483,330	61,483,330	61,483,330	65,868,000	65,868,000	65,868,000	76,610,830	76,610,830	76,610,830
N purchased (000 tons)	35.163	35.158	35.158	42.471	42.471	42.471	51.435	51.435	51.435
P purchased (000 tons)	0.005	0	0	0.005	0.005	0.005	11.859	11.859	11.859
K purchased (000 tons)	33.996	33.996	33.996	33.996	33.996	33.996	37.272	37.272	37.272
Total litter used (tons)	1,623,933	1,624,100	1,624,100	1,623,933	1,623,933	1,623,933	1,638,391	1,638,391	1,638,391
Total cost of fertilizer	31,979,760	31,973,840	31,973,840	36,363,480	36,363,480	36,363,480	49,429,190	49,429,190	49,429,190

Table 4. Optimal Amount of Broiler Litter Used Under Three Scenarios and Three Nutrient Constraint Situations (First Year)

	Constraints						
		Based on nutrient release			Based on nutrient availability		
Items	Chemical fertilizer	N and P equality	N, P, and K equality	P equality	N, P, and K equality	N and P equality	P equality
Total cost (dollars)	97,039,540	64,026,460	64,026,460	64,026,460	75,293,560	75,293,560	75,293,560
N purchased (000 tons)	85.506	39.402	39.402	39.402	49.240	49.240	49.240
P purchased (000 tons)	48.723	0.005	0.005	0.005	11.859	11.859	11.859
K purchased (000 tons)	57.661	33.996	33.996	33.996	37.272	37.272	37.272
Total litter used (tons)	0	1,623,933	1,623,933	1,623,933	1,638,391	1,638,391	1,638,391
Total cost of fertilizer	97,039,540	34,522,840	34,522,840	34,522,840	48,111,920	48,111,920	48,111,920

Therefore, adding the N and P equality constraint does not change the solution, perhaps because the litter contains more nitrogen and phosphorus than potassium.

The second scenario involved broiler litter application and transportation decisions made based on the nutrient release from the litter. We took into consideration the fact that not all of the nutrients are released from the broiler litter for crop use. Under this scenario, we found that the total cost of meeting the nutrient need is 32% less than with the chemical fertilizer only option if NPK equality constraints are imposed. In this scenario, chemical fertilizer comprises 55% of the total cost. An optimal amount of litter use was less than the total litter now being produced in the state. Based on these criteria, there is 0.9% excessive litter production in the state. Under the second scenario, all of the solutions obtained are similar regardless of whether NPK, NP, or P constraints were imposed in the model.

The third scenario is based on the nutrients available from broiler litter. The cost of meeting the nutrient needs of the four crops was higher than in the other two scenarios. The cost was about 21% lower than the chemical fertilizer only option when all NPK equality constraints are imposed. The central planner spent about 65% of the total cost on chemical fertilizers. All of the broiler litter produced in the state was used. The solution did not change when the constraints were changed to N and P equality or P only equality.

Since not all of the nutrients are released in the first year, we also ran the model based on the nutrient amount in the fifth year of continuous application of broiler litter to the crops. Of the scenarios investigated, environmentalists are concerned with the over-application of litter based on the nutrient availability. Therefore, we restricted our analysis for the fifth-year nutrient availability situation. This means that we assumed that farmers apply broiler litter continuously in the same fields based on the nutrient needs of the crops. We found that all of the litter produced in Alabama is utilized whether NPK, NP, or P equality is enforced. Because the amount of N released from litter is slightly higher, it becomes cheaper to supply the nutrient needs of the state in this scenario. The total cost of meeting the nutrient need is 34% less than the chemical fertilizer only option.

If a transportation model is developed based on the availability of nutrients in the fifth year, litter is completely utilized regardless of what nutrient constraint equality is imposed in the model. The result is shown in Table 4. The cost saving in this case is 22.3%, slightly higher than the first year (21%) of the same scenario. Litter is not completely utilized when the analysis is done with the assumption of nutrient release. If litter is applied based on the availability rule, all of the litter would be utilized in the fifth year.

Since it is most likely that farmers would apply broiler litter based on the nutrient availability, the result obtained from this scenario may be the most important for policy makers to formulate a policy to curtail the over-production of litter in a given sub-basin level. Before moving to the policy formulation section, we will first describe the transportation pattern of the litter from the top 10 litter-producing counties under the availability rule in the first year of broiler litter application. We will show the complete transportation patterns obtained in the optimal solution. We will then analyze the sensitivity of change in hauling cost assuming that litter application is based on nutrient availability in the litter.

Transportation Routes Used and Amount of Nutrient Used

Space constraints will not allow us to describe transportation patterns under each alternative analyzed. Therefore, we will focus our attention on the phosphorus equality constraint of the nutrient availability scenario in the first and fifth years. We found that the same transportation routes are used in both the first and the fifth years and that the amount of litter transported along each route is the same in the first and the fifth years. Table 5 details the transportation of litter used in each county in Alabama. The litter transportation routes selected here indicate that even though we specified 4,489 routes in the model, only 88 routes are used in the optimal solution. In this section we highlight the details on the transportation of litter from the top 10 broiler litter-producing counties.

Table 6 shows the amount of litter used within the county and transferred out of the county for the top 10 litter-producing counties. Cullman County which produces the highest amount of litter in the state, transfers litter to nine other counties and within its own borders. The highest amount of litter is transferred within the county to meet crop nutrient needs. The other counties receiving the litter are Morgan, Limestone, Lawrence, Walker, Shelby, Chilton, Jefferson, Bibb, and Winston, in order from the highest to the lowest. These counties are not adjacent to Cullman County. In fact, they compete with other counties to get the litter. We found that the amount of litter transported is based on how far the destination county is from the originating county. The least amount of litter is transported to the county furthest away.

Blount County litter is transported within the county and to four other counties. It ranks second to Cullman County in numbers of counties to which it transports litter. Table 6 shows the destination of litter produced in the top 10 litter-producing counties. Among them, only Walker County did not keep litter for its own use; it obtained litter from Cullman County to meet its crop nutrient needs. Seven of these 10 counties utilized the highest amount of litter within their borders.

SENSITIVITY ANALYSIS

Two major concerns about the litter transport rule based on the phosphorus constraint are increased hauling costs and changes in litter production and crop acreage. We address both of these issues in this section.

Table 5. Transfer of Litter from One County to Another County Based on Nutrient Availability in the First and Fifth Years (NPK, NP, and P Equality Constraints

First Year			Fifth Year		
From county	To county	Litter transferred (tons)	From county	To county	Litter transferred (tons)
Jackson	Jackson	21,585.04	Jackson	Jackson	21,585.04
Jackson	Madison	24,939.20	Jackson	Madison	24,939.20
Limestone	Limestone	6,882.96	Limestone	Limestone	6,882.96
Lauderdale	Lauderdale	3,288.97	Lauderdale	Lauderdale	3,288.97
Lauderdale	Colbert	1,457.03	Lauderdale	Colbert	1,457.03
DeKalb	Jackson	46,326.07	DeKalb	Jackson	46,326.07
DeKalb	DeKalb	73,955.56	DeKalb	DeKalb	73,955.56
DeKalb	Cherokee	31,091,38	DeKalb	Cherokee	31,091,38
Colbert	Lauderdale	15,323.28	Colbert	Lauderdale	15,323.28
Lawrence	Lawrence	53,707.92	Lawrence	Lawrence	53,707.92
Morgan	Limestone	46,174.80	Morgan	Limestone	46,174.80
Marshall	Madison	59,733.66	Marshall	Madison	59,733.66
Marshall	Marshall	49,644.44	Marshall	Marshall	49,644.44
Cherokee	Cherokee	6,686.40	Cherokee	Cherokee	6,686.40
Franklin	Colbert	49,254.08	Franklin	Colbert	49,254.08
Franklin	Franklin	25,600.00	Franklin	Franklin	25,600.00
Cullman	Limestone	44,994.86	Cullman	Limestone	44,994.86
Cullman	Lawrence	31,669.86	Cullman	Lawrence	31,669.86
Cullman	Morgan	54,444.44	Cullman	Morgan	54,444.44
Cullman	Cullman	73,955.56	Cullman	Cullman	73,955.56
Cullman	Winston	5,168.58	Cullman	Winston	5,168.58
Cullman	Walker	21,333.33	Cullman	Walker	21,333.33
Cullman	Jefferson	8,888.89	Cullman	Jefferson	8,888.89
Cullman	Shelby	20,000.00	Cullman	Shelby	20,000.00
Cullman	Bibb	6,222.22	Cullman	Bibb	6,222.22
Cullman	Chilton	12,405.56	Cullman	Chilton	12,405.56
Blount	Blount	34,933.33	Blount	Blount	34,933.33
Blount	Etowah	20,854.68	Blount	Etowah	20,854.68
Blount	St. Clair	25,244.44	Blount	St. Clair	25,244.44
Blount	Talladega	10,720.40	Blount	Talladega	10,720.40
Blount	Chilton	5,905.55	Blount	Chilton	5,905.55
Etowah	Etowah	9,411.99	Etowah	Etowah	9,411.99
Etowah	Calhoun	26,167.05	Etowah	Calhoun	26,167.05
Winston	Winston	13,498.09	Winston	Winston	13,498.09
Winston	Marion	21,233.49	Winston	Marion	21,233.49
Winston	Fayette	14,621.78	Winston	Fayette	14,621.78
Marion	Marion	1,610.95	Marion	Marion	1,610.95
Marion	Lamar	15,118.49	Marion	Lamar	15,118.49
Cleburne	Cleburne	8,488.89	Cleburne	Cleburne	8,488.89
Cleburne	Randolph	14,133.33	Cleburne	Randolph	14,133.33
Cleburne	Clay	2,266.98	Cleburne	Clay	2,266.98
Calhoun	Calhoun	3,077.40	Calhoun	Calhoun	3,077.40
Calhoun	Clay	11,955.24	Calhoun	Clay	11,955.24

Table 5. (Cont'd.)

First Year			Fifth Year		
From county	To county	Litter transferred (tons)	From county	To county	Litter transferred (tons)
St. Clair	Talladega	23,679.60	St. Clair	Talladega	23,679.60
Walker	Tuscaloosa	28,711.11	Walker	Tuscaloosa	28,711.11
Walker	Hale	11,082.47	Walker	Hale	11,082.47
Walker	Perry	4,739.86	Walker	Perry	4,739.86
Lamar	Lamar	2,570.40	Lamar	Lamar	2,570.40
Fayette	Fayette	400.44	Fayette	Fayette	400.44
Fayette	Pickens	1,543.32	Fayette	Pickens	1,543.32
Talladega	Coosa	6,400.00	Talladega	Coosa	6,400.00
Talladega	Elmore	5,412.08	Talladega	Elmore	5,412.08
Randolph	Chambers	12,266.67	Randolph	Chambers	12,266.67
Randolph	Lee	7,728.69	Randolph	Lee	7,728.69
Clay	Tallapoosa	7,822.22	Clay	Tallapoosa	7,822.22
Clay	Elmore	11,506.18	Clay	Elmore	11,506.18
Tuscaloosa	Hale	12,428.64	Tuscaloosa	Hale	12,428.64
Pickens	Pickens	21,523.35	Pickens	Pickens	21,523.35
Pickens	Greene	15,555.56	Pickens	Greene	15,555.56
Pickens	Sumter	20,533.33	Pickens	Sumter	20,533.33
Tallapoosa	Macon	1,073.52	Tallapoosa	Macon	1,073.52
Hale	Perry	1,535.52	Hale	Perry	1,535.52
Montgomery	Montgomery	8,621.76	Montgomery	Montgomery	8,621.76
Lowndes	Lowndes	11,694.48	Lowndes	Lowndes	11,694.48
Bullock	Bullock	3,259.20	Bullock	Bullock	3,259.20
Barbour	Henry	21,710.64	Barbour	Henry	21,710.64
Choctaw	Choctaw	3,674.16	Choctaw	Choctaw	3,674.16
Pike	Bullock	11,940.80	Pike	Bullock	11,940.80
Pike	Pike	33,499.84	Pike	Pike	33,499.84
Crenshaw	Pike	5,166.83	Crenshaw	Pike	5,166.83
Crenshaw	Crenshaw	16,037.74	Crenshaw	Crenshaw	16,037.74
Crenshaw	Butler	17,740.74	Crenshaw	Butler	17,740.74
Crenshaw	Covington	10,629.82	Crenshaw	Covington	10,629.82
Butler	Conecuh	18,186.44	Butler	Conecuh	18,186.44
Butler	Escambia	3,907.24	Butler	Escambia	3,907.24
Henry	Henry	8,672.16	Henry	Henry	8,672.16
Monroe	Escambia	8,621.76	Monroe	Escambia	8,621.76
Dale	Houston	30,955.68	Dale	Houston	30,955.68
Coffee	Dale	25,066.67	Coffee	Dale	25,066.67
Coffee	Coffee	41,733.33	Coffee	Coffee	41,733.33
Coffee	Covington	15,458.26	Coffee	Covington	15,458.26
Coffee	Geneva	8,802.78	Coffee	Geneva	8,802.78
Washington	Washington	4,420.08	Washington	Washington	4,420.08
Covington	Covington	10,134.15	Covington	Covington	10,134.15
Covington	Escambia	24,704.01	Covington	Escambia	24,704.01
Houston	Houston	3,302.88	Houston	Houston	3,302.88
Geneva	Houston	21,741.44	Geneva	Houston	21,741.44

Table 6. Transportation Routes Used by Top 10 Counties and the Amount of Litter Transported from These Counties

From county	To county	Distance (miles)	Litter amount (tons)	
Blount	Chilton	79.7		5,905.55
Blount	Talladega	47.7		10,720.40
Blount	Etowah	29.4		20,854.68
Blount	St. Clair	23.4		25,244.44
Blount	Blount	14.5		34,933.33
Blount total			**97,658.40**	
Coffee	Geneva	23.4		8,802.78
Coffee	Covington	28.1		15,458.26
Coffee	Dale	22		25,066.67
Coffee	Coffee	14.6		41,733.33
Coffee total			**91,061.04**	
Cullman	Winston	27.6		5,168.58
Cullman	Bibb	75.2		6,222.22
Cullman	Jefferson	39.1		8,888.89
Cullman	Chilton	86.8		12,405.56
Cullman	Shelby	56.9		20,000.00
Cullman	Walker	32.5		21,333.33
Cullman	Lawrence	39.7		31,669.86
Cullman	Limestone	48.3		44,994.86
Cullman	Morgan	26.6		54,444.44
Cullman	Cullman	15.5		73,955.56
Cullman total			**370,144.34**	
DeKalb	Cherokee	19.9		31,091.38
DeKalb	Jackson	23.5		46,326.07
DeKalb	DeKalb	15.7		73,955.56
DeKalb total			**151,373.01**	
Geneva	Houston	32.8		21,741.44
Geneva	Geneva	13.7		38,219.44
Geneva total			**59,960.88**	
Lawrence	Lawrence	15.1		53,707.92
Lawrence total			**53,707.92**	
Marshall	Marshall	14		49,644.44
Marshall	Madison	29.8		59,733.66
Marshall total			**109,378.10**	

Table 6. (Cont'd.)

From county	To county	Distance (miles)	Litter amount (tons)
Pickens	Greene	28	15,555.56
Pickens	Sumter	42.4	20,533.33
Pickens	Pickens	16.8	21,523.35
Pickens total			**57,612.24**
Walker	Perry	81.9	4,739.86
Walker	Hale	72.4	11,082.47
Walker	Tuscaloosa	32.9	28,711.11
Walker total			**44,533.44**
Winston	Winston	14.2	13,498.09
Winston	Fayette	36.8	14,621.78
Winston	Marion	31.6	21,233.49
Winston total			**49,353.36**

Effects of Change in Hauling Cost

Table 7 shows the effect of hauling cost change on litter use, chemical fertilizer cost, and the total cost of meeting the nutrient needs of the selected crops in Alabama. When the hauling cost is $0.20 per ton per mile, there would be complete utilization of broiler litter produced in the state. When the hauling cost increases to $0.22 per ton per mile, there would be less than complete utilization. The objective function shows a 5.8% increase in cost compared to the base period. There would be 38,304 tons of litter (2.3%) left in this situation. The total share of chemical fertilizer used increases as the per unit cost of hauling litter increases. We wanted to find the break point when the central planner would switch completely to chemical fertilizer use. We found that when the hauling cost increased to $1.56 per ton per mile, there would be no litter utilization at all. All of the nutrient needs would be met by using chemical fertilizer. In this situation, the cost is exactly the same as when only chemical fertilizer is used. Although it is highly unlikely that the cost of hauling would go that high, it does provide a scenario with no litter utilization.

We also ran the sensitivity analysis under the scenario when litter has been used continuously for five years. Because nitrogen availability increases as litter is applied continuously in the same field, we did the sensitivity analysis of hauling cost change for the fifth year. When the hauling cost is $0.23 per ton per mile, the central planner did not utilize the litter completely. We found that in

Table 7. Effect of Hauling Cost Change in Broiler Litter Application Based on Nutrient Availability Under Phosphorus Equality Constraint

	First year Hauling cost (dollars per ton per mile)					Fifth year Hauling cost (dollar per ton per mile)				
Items	0.10	0.21	0.22	1.55	1.56	0.10	0.22	0.23	1.61	1.62
Objective function ($)	76,610,830	81,001,360	81,371,610	97,037,350	97,039,540	75,293,560	80,073,250	80,453,030	97,038,260	97,039,540
N purchased (000 tons)	51,435	51,435	52,232	84,527	85,505	49,240	49,240	50,087	84,465	85,505
P purchased (000 tons)	11,859	11,859	12,721	47,665	57,660	11,859	11,859	12,721	47,665	48,723
K purchased (000 tons)	37,271	38,717	38,794	56,155	48,723	37,272	38,717	38,794	56,156	57,660
Total litter used (000 tons)	1,638,391	1,638,391	1,600,081	47,022	0	1,638,391	1,638,391	1,600,081	47,022	0
Total cost of fertilizer ($ millions)	49.40	49.89	50.87	95.38	97.04	48.11	48.57	49.59	95.34	97.04

the fifth year situation, litter can be transported and utilized completely if the hauling cost is \$0.01 per ton per mile higher than in the first year. When the hauling cost is \$1.62 per ton per mile, there would be no utilization of litter at all. This amount is \$0.07 higher than the base period. We determined that the concern that it is not possible to use all of the litter at the current or base hauling cost is not valid.

Effect of Change in Future Crop Acreage and Broiler Production

Tables 8 and 9 show the litter utilization based on the future projection of growth on poultry and crop acreage. The projection is based on 10 years of data (1989-1998) on crop acreage and broiler production obtained from the Alabama Agricultural Statistics Service. Figure 2 demonstrates that on average corn, cotton, hay, and broilers show positive growth rates whereas wheat shows a negative growth rate.

Table 8 show litter utilization based on the assumption that both litter and crop acreage change according to the trend observed from the historical data. We analyzed and projected the litter use scenario for 10 years based on this assumption. In the first year litter growth is projected at 4.1%. The total cost of meeting the state's nutrient needs is \$77.6 million. Total chemical fertilizer cost is \$49.2 million. All of the litter produced in the state is utilized in this scenario.

The overall positive growth rate of both crop acreage and litter change causes costs to increases slowly during the 10-year period. The analysis is based on the phosphorus constraint and nutrient availability scenario. In the analysis, N availability from the litter is increased each year up to the fifth year and then leveled off. We assumed that litter and litter hauling costs would remain at the base level over the projection period. The result shows that as we move from the first to the tenth year, the total cost of chemical fertilizer decreases slowly. This is because more and more nutrient needs are met from broiler production. The purchased amount of N, P, and K fertilizer shows a linear decrease over the time period. At the end of the tenth year, the total cost of meeting the nutrient needs was \$85.3 million, substantially lower than the chemical fertilizer only option in the base period scenario.

Another possible scenario is shown in Table 9. In this case, we performed the analysis assuming that only litter production increases following the historical growth pattern, but that crop acreage remains constant. All other assumptions are the same as reflected in Table 8 results. We found that litter surplus occurs only at the seventh year, when there is a 12,600 ton surplus. The cost of meeting the nutrient needs for the state also declines as we progress toward the seventh year. The amount of NPK purchased and the total cost of the chemical fertilizer also declines as we go from the first to the seventh year.

Table 8. Projected Growth of Broiler and Crop Acreage for 10 Years and Litter Utilization Based on Nutrient Availability in Litter Under Phosphorus Equality Constraints

Items	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Total cost ($ millions)	77.6	77.8	78.5	79.3	80.2	81.2	82.2	83.2	84.3	85.3
N purchased (000 tons)	51.7	50.6	50.2	50.2	50.1	50.3	50.4	50.6	50.8	51.0
P purchased (000 tons)	11.0	10.2	9.4	8.5	6.8	6.8	6.0	5.1	4.3	3.5
K purchased (000 tons)	37.6	37.5	37.5	37.9	38.2	38.2	38.0	37.8	37.6	37.3
Total fertilizer cost ($ millions)	49.2	48.1	47.4	47.0	46.2	46.1	45.8	45.4	44.9	44.4
Litter used (000 tons)	1,707	1,775	1,844	1,912	1,980	2,049	2,118	2,186	2,255	2,323
Projected litter produced (000 tons)	1,707	1,775	1,844	1,912	1,980	2,049	2,118	2,186	2,255	2,323
Litter surplus (000 tons)	0	0	0	0	0	0	0	0	0	0

Table 9. Amount of Litter Use with Projected Growth in Broiler Production but Status Quo in Present Crop Acreage Based on Availability of Nutrients in Litter Under Phosphorus Equality Constraints

Items	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7
Total cost ($ millions)	75.9	74.4	73.3	72.5	71.6	71.0	70.6
N purchased (000 tons)	50.0	47.2	45.1	43.4	41.7	40.1	38.9
P purchased (000 tons)	10.3	8.8	7.2	5.7	4.2	2.6	1.3
K purchased (000 tons)	36.3	34.9	34.3	33.0	31.5	29.8	28.0
Total fertilizer cost ($ millions)	47.4	44.1	42.1	39.8	37.4	35.1	33.0
Litter used (000 tons)	1,707	1,775	1,844	1,912	1,981	2,049	2,105
Projected litter produced (000 tons)	1,707	1,775	1,844	1,912	1,981	2,049	2,118
Litter surplus (000 tons)	0	0	0	0	0	0	12.6

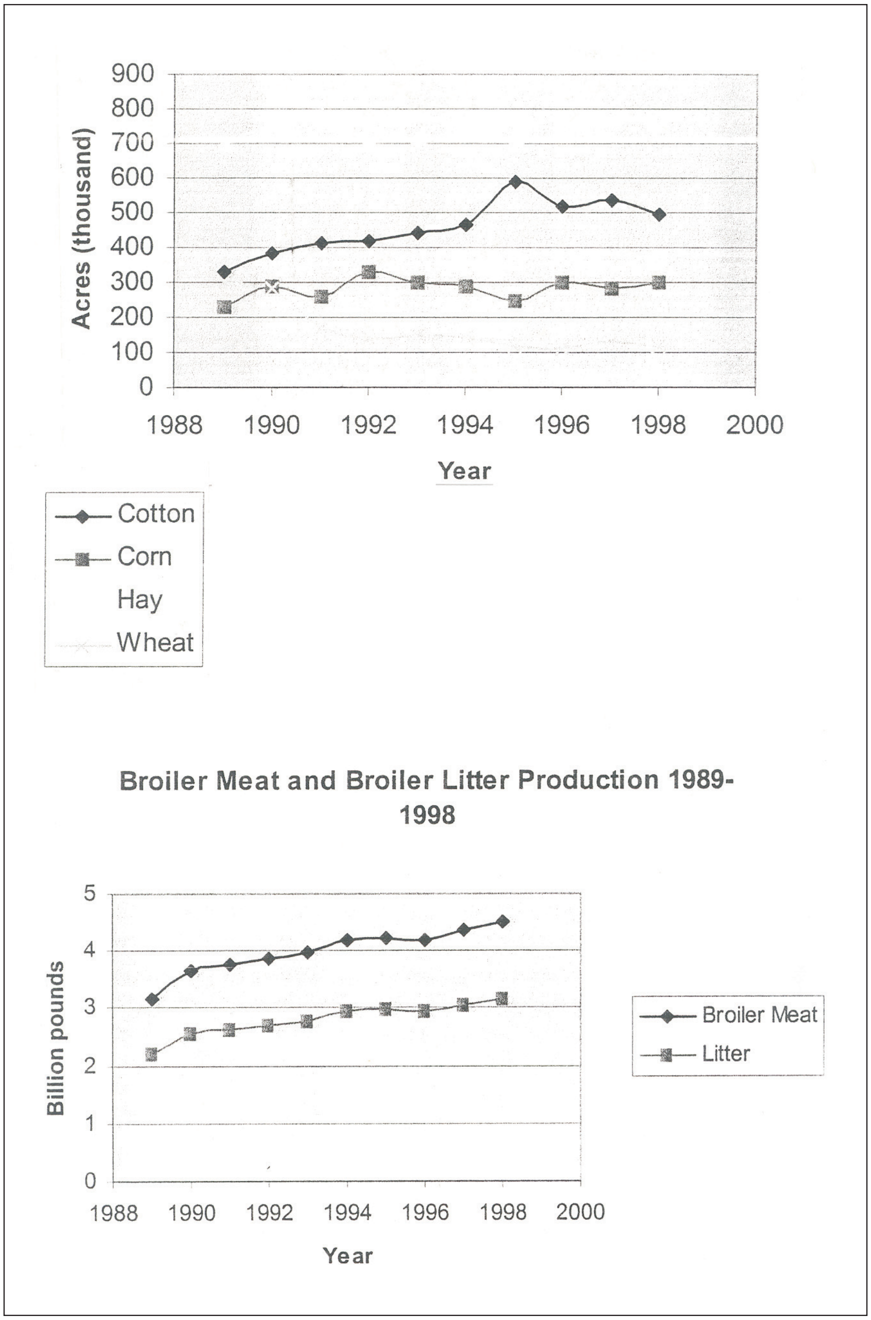

Figure 2. Acreage and broiler production in Alabama 1989-1998.

POLICY PRESCRIPTIONS

We have found that except for the nutrient content situation, the amount of broiler litter produced in Alabama could be utilized completely if used as a source of nutrients in crop production. Broiler litter application should be based on nutrient availability rather than nutrient content in the litter. The amount of litter applied to crops should be carefully monitored to comply with the best management practices suggested by the local Natural Resource Conservation Service.

When projecting broiler litter amount and crop production acreage based on historical data, we found that all of the broiler litter produced within 10 years of the analysis would be utilized. Crop acreage in general has shown a tendency to decrease as demand for residential development increases. In that case, as we have found, litter production may be surplus after six years from the current analysis period. There is thus a need for policy tools to curtail litter production after that period. We suggest a few possible policy tools to overcome excessive broiler litter production in Alabama.

Govindasamy and Cochran have compared four policy scenarios in terms of efficiency and practicality to manage land application of poultry litter [19]. They found that tax per ton of litter and land tax achieved the same result. Mitchell has suggested that marketable permit system offers a better alternative for broiler litter application in controlling nonpoint source pollution caused by phosphorus pollution in The Illinois River Basin [20]. In the present context of southern agricultural system, the abatement cost required for removing phosphorus pollution from waterbodies and the growth rate of broiler production are uncertain. Therefore to achieve the desired level of litter production, we suggest a mix policy instrument similar to one proposed by Roberts and Spence [21] and explained by Baumol and Oates [22]. The mix policy employs marketable permits supplemented by an effluent tax and a subsidy. By following this mix policy approach, we should be able to reward broiler producers who under-produce phosphorus allowed by their permit and punish those who produce phosphorus in excess of the permitted level. The marketable permits should be distributed based on the phosphorus amount equivalent of broiler litter production by a farm. Further, the numbers of marketable permits should be distributed based on the combination of current litter use potential and adoption of broiler litter as plant nutrient sources by each county in the state. We assume that there exists a market for trading these permits that would help to obtain an equilibrium price permit. Let us assume that the equilibrium permit price is p. We assume that the regulator allows broiler producers to produce broiler litter without permits or in excess of the quantity authorized by their permit holding, but charges, an effluent tax, t, per unit of such production. Finally, the regulator offers the polluter subsidy, s, per unit for any unused permits where $s \leq t$. In the equilibrium, the following condition should hold as well:

$$s \leq p \leq t. \qquad (5)$$

If p were greater than t, no one would purchase a permit but would pay the effluent charge instead, so p would have to be lowered. On the other hand, if s exceeded p, it would pay to purchase as many permits as were available and hold them unused at a profit of s-p per unit; but obviously no one would be willing to sell a permit at that price. If $s = 0$, $t = \infty$, the mixed system would completely eliminate tax and subsidy and would transfer into the permit system.

It follows that if the three regulator-controlled parameters in the system (s, t, and the number of permits issued, n) are selected so as to maximize expected welfare, the result must be at least as desirable as either a pure permit or a pure effluent fee. The mixed system can be illustrated using Figure 3. The system represents a compromise between the horizontal effluent curve, t, and pure variable payment f(l), where l is the total amount of phosphorus produced in the litter. It is a step function that constitutes an approximation to the marginal benefit curve as shown in Figure 3. There are three regulatory decision variables, l*, t, and s. For an emission reduction less than the prescribed quantity, l*, there is an

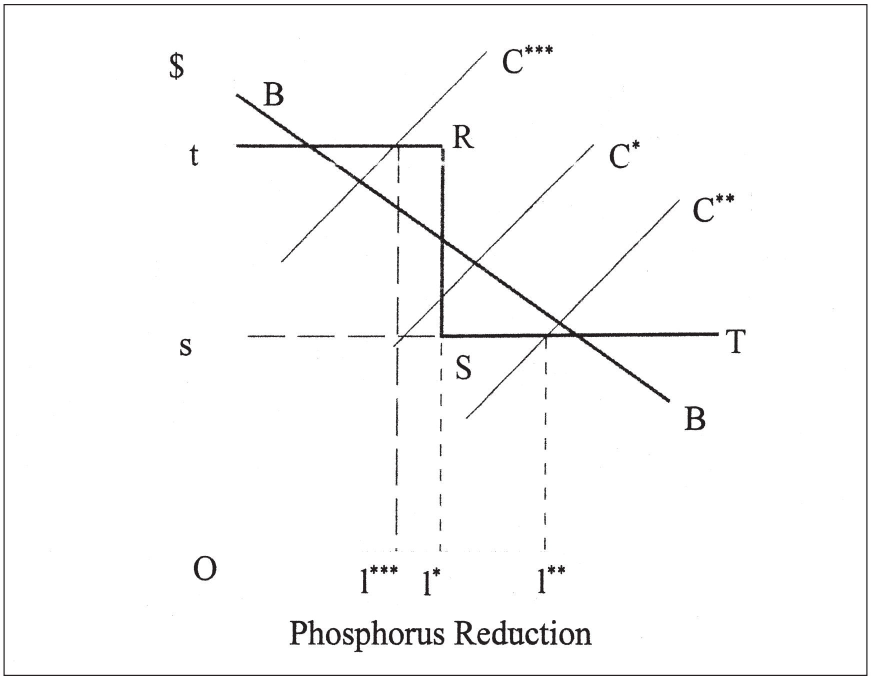

Figure 3. A mixed policy approach to reduce phosphorus pollution in Alabama watersheds.

effluent fee, t, whereas for emissions reductions greater than l*, incremental emissions have a low opportunity cost (equivalent to an effluent charge), s. Along the vertical segment SR, the effective fee is some value p where t > p > s. The implicit effluent locus tRST is a better approximation to the marginal benefit curve BB than is any horizontal line. We also see how extreme errors in the regulator's estimate of marginal control costs (like curves C** and C***) can lead to adaptation in the value of l, unlike a pure permit system.

CONCLUSIONS

Our study indicates that it is possible to solve the excess litter problem by transporting litter from the concentrated broiler-producing counties to other counties in Alabama based on the phosphorus consistent rule. This is true even if there is a projected broiler litter growth compatible with the historical rate in coming years. Our analysis assumes that litter can be transferred from one county to another like any market commodity. Of course, this requires the acceptance of litter by crop producers and government assistance to make litter an acceptable alternative to chemical fertilizers. This study provides the evidence that litter can be economically transported out of the major broiler-producing counties to minimize environmental problems in the most problematic areas. The study did not consider the benefit of organic matter development that may be realized if broiler litter is used in the long run.

If this solution is to be applied to the free market individual farmer situation, smoothly operating market mechanisms for litter transportation, litter purchase and responsible use of litter must be in place. If the adoption rate among individual farmers is low, we should work to either increase awareness among farmers about the cost-saving benefit of litter use or use the current adoption rate as a benchmark to formulate environmental policy tools. Few of the reasons for the low adoption of broiler litter as crop nutrient source are incomplete information on the long- run benefit of litter application, fear of land compaction from heavy tractor movement on the field, nonuniform application, and variable nutrient content of the litter. The outcome of this model will be helpful in formulating environmental policy tools such as zonal taxes, zonal permits, or zonal quotas so that overproduction of litter can be avoided to protect our water resources from nitrogen or phosphorus pollution.

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