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Title of paper: An Evaluation of an Economic Strategy for Preventing Water Pollution Using a Phosphorus Consistent Transportation Model: A Case of Broiler Litter Management

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Series: LSU Agecon 100-2002

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Summary of the paper: We calculated the profitability of using broiler litter as a source of plant nutrient using a phosphorus consistent litter application rule. We found that each ton of litter can be transferred cost effectively up to 164 miles from the production facilities. The minimum cost phosphorus consistent transportation model developed to meet the nutrient needs of 29 counties in North Alabama revealed that not all the litter can be utilized in the region. The total cost for nutrient supply increased when transportation of litter from heavily surplus counties were prioritized. The effect of chemical fertilizer price change minimally affected the total litter use.

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JEL codes: Q000, Q100

An Evaluation of an Economic Strategy for Preventing Water Pollution Using a Phosphorus Consistent Transportation Model: A Case of Broiler Litter Management

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ABSTRACT

We calculated the profitability of using broiler litter as a source of plant nutrient using a phosphorus consistent litter application rule. We found that each ton of litter can be transferred cost effectively up to 164 miles from the production facilities. The minimum cost phosphorus consistent transportation model developed to meet the nutrient needs of 29 counties in North Alabama revealed that not all the litter can be utilized in the region. The total cost for nutrient supply increased when transportation of litter from heavily surplus counties were prioritized. The effect of chemical fertilizer price change minimally affected the total litter use.

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An Evaluation of an Economic Strategy for Preventing Water Pollution Using a Phosphorus Consistent Transportation Model: A Case of Broiler Litter Management

Alabama ranks third in broiler production in the United States (Census of Agriculture). In 1999, 972.2 million broilers were produced in Alabama which generated $1.88 billion in revenue to the State. Broiler production is also the number one agricultural enterprise in the State, accounting for approximately 55 percent of the total farm receipts. Although it is regarded as the most valuable agricultural industry in the State, broiler production is also responsible for a huge amount of litter production, the lack of proper disposal of which can cause air and water quality problems. The estimated amount of broiler litter production in Alabama is about 1.5 million tons each year. Commonly used vertical integration has forced broiler producers to concentrate in a relatively small area resulting in a high concentration of broiler operations in a few counties in North Alabama. For example, the five major broiler production counties in the State, namely Cullman, Blount, DeKalb, Marshall, and Walker are located in North Alabama. It is of utmost importance to assess the economics of transferring broiler litter from the counties where litter production is excessively high to the counties where litter can be used as a source of crop nutrients without causing further harm to the environment. Further, states with concentrated broiler production facilities such as Alabama are under the scrutiny of federal regulations that have forced them to support and implement new regulations for better manure management in order to protect water quality (USEPA). Therefore, it is important that we assess the alternatives of managing broiler litter so that once implemented the federal regulations have minimum impact on the broiler industry and hence the local economy.

Phosphorus remains a primary element of concern from the surface water quality aspect. Phosphorus is generally considered a limiting nutrient for eutrophication in fresh water. Broiler litter contains a high concentration of water soluble phosphorus (often more than 90 mg per pound) making it susceptible to runoff.

Several studies in the past considered nitrogen management as a major issue in agriculture (VanDyke, Bosch, and Pease; Reinhard, Lovell, and Thijssen; Piot-Lepetit and Vermersch). However, in concentrated animal production and manure application areas, phosphorus pollution has been a concern which is addressed by many researchers lately (Boland, Preckel, and Foster; Bosch, Zhu, and Kornegay; Goetz and Zilberman; Johnsen; McCann and Easter; Schnitkey and Miranda). Most of these studies on phosphorus pollution have focused on the externality aspect of phosphorus pollution especially finding the optimal policy to control phosphorus pollution. Others have emphasized restrictions on phosphorus and taxes on phosphorus application to avoid the eutrophication problem. Restriction on animal production and phosphorus tax are only effective if we know whether it is profitable to apply broiler litter as a crop nutrient source, the area where litter can be applied, and each county's potential for production and consumption of broiler litter. Our approach addresses these concerns left out in earlier research by using the phosphorus consistent rule to find the maximum amount of litter that can be utilized in crop producing counties located on or nearby the broiler production counties. A phosphorus consistent rule is defined as the application of litter based on the phosphorus recommendation rate for a crop in the region by the Cooperative Extension Service. We further investigated the allocation decision of a central planner who wants to reduce the cost of meeting the total nutrient needs of crop production in the 29 county regions of North Alabama with environmental constraints. We developed a transportation model to find the most cost efficient routes for litter transfer to meet the total nutrient demand of the five major crops grown in the area. We calculated the extra cost required above the minimum cost solution when there is a priority to transfer out excess litter from the four most problematic counties in the region. We also showed the change in the total litter use and cost when the price of nitrogen fertilizer is parametrically varied.

Broiler Litter as a Crop Nutrient Source

Among the several solutions outlined for the broiler litter problem in the region, its use 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 macro nutrient composition of broiler litter is 62:60:40 N:P_2O_5:K_2O pounds per ton. Current estimates show that the average nutrient value of broiler litter in Alabama is $35.60 per ton, but the lack of a well operating market and imperfect information on the benefit of responsible long-term application of broiler litter results in its sell for approximately $10 per ton.

Since all the nutrients from litter are not available to the crop at the same year it is applied, we assumed that only 50 percent of organic nitrogen is released during the first year, 12 percent in the second year, 5 percent in the third year, and 2 percent each in the fourth and fifth year. We also assumed that litter contains 0.9 percent organic nitrogen and 2.2 percent inorganic nitrogen. Additionally, we assumed that only 80 percent of inorganic N, 71 percent of organic N, 75 percent of phosphorus, and 75 percent of potassium are available. The chemical fertilizer cost for our calculation is obtained from the Alabama Cooperative Extension System (ACES). According to the ACES report, the custom applied prices of N, P_2O_5, and K_2O in the region are 0.30, 0.28, and 0.16 dollars per pound, respectively (Crews, Goodman, and Runge). These prices include the costs for hauling and application. For example, the ACES recommended amount of fertilizer for cotton and corn for North Alabama is 60:40:40 and 120:40:40 N, P_2O_5, K_2O lbs/acre, respectively. If chemical fertilizer is applied to meet this need, it will cost $35.60 and $53.60 per acre of cotton and corn, respectively. Given the assumption of the nutrient content in broiler litter and prevalent rates of 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 of the phosphorus requirement provides a cost saving of $18.52 per acre compared to the chemical fertilizer use. This indicates that litter can be transferred up to 164 miles from the production facilities. This distance is sufficient to transfer litter economically from the concentrated litter production counties such as Blount, Cullman, DeKalb, and Marshall to the major crop production counties such as Madison and Limestone. Table 1 shows the breakeven distance for the litter transportation in two major crops in the region based on the assumptions set forth. Because of carryover of nutrient from one year to another until the fifth year, litter can be transported further as litter application continues year after year. For example, in cotton litter can be transported only up to 136 miles in the first year but the breakeven distance increases up to 164 miles over the fifth year.

We found that it is profitable to use broiler litter as a source of nutrients in the region. We have also found that broiler litter can be transferred up to 164 miles from the production facilities. Does this mean that there is a potential of broiler litter application in the region to meet the nutrient needs? What if there is a central planner who wants to minimize the cost for meeting the nutrient needs of the region while also considering the environmental constraints? In other words, how should the nutrient needs of the region be managed given that there is excessive litter production in the region?

To solve these concerns, we developed a linear programming model. In this model, we assumed that a central planner is responsible for meeting the nutrients need of twenty-nine counties. The central planner's objective is to reduce the total cost of meeting the nutrients in the region while being environmentally consistent so that he does not over apply phosphorus in crop production. The central planner can meet the nutrient needs of the region either by applying chemical fertilizer or by applying litter by constraining himself within the boundary of all broiler litter production and crop acreage in the region. Additionally, the phosphorus consistent rule for litter application is considered for the four major crops grown in the region namely corn, cotton, wheat, and hay. We avoided pastureland because most of the pastureland in the region already has a high concentration of phosphorus in the soil. We also avoided legume crop from consideration as the Alabama Cooperative Extension Service does not recommend applying nitrogen for these crops and if litter is applied based on the phosphorus consistent rule, nitrogen will be over applied. Even though the model considered uses the phosphorus consistent rule, we carefully avoided nitrogen over application in these crops. There are choices of meeting the nutrient needs either from broiler litter or from the chemical fertilizer but phosphorus application is a binding constraint in the model. The objectives of the optimization model are:

1. To minimize the total expenditure on plant nutrient needs by substituting broiler litter for chemical fertilizer as a source of plant nutrients in the selected 29 counties of North Alabama,
2. To analyze the economic impact of transferring broiler litter as a substitute of chemical fertilizers in North Alabama,
3. To analyze the possibilities of transferring broiler litter from the counties of surplus production to counties of nutrient deficits,
4. To select the most efficient transportation routes in terms of transportation cost, and,
5. To provide a broad overview of broiler litter transportation issues by covering 29 counties of North Alabama.

Model

To meet the objectives outlined above, a central planner's objective function and constraints can be written as follows:

$$(1) \qquad \underset{W,X,Y}{Min\ Z} = \sum_{a=1}^{4} \sum_{k=1}^{29} L_{ak} W_{ak} + \sum_{a=1}^{4} \sum_{k=1}^{29} \sum_{t=1}^{3} P_t X_{akt} + \sum_{i=1}^{16} \sum_{j=17}^{29} T D_{ij} Y_{ij}$$

Subject to:

$$(2) \qquad \sum_{t=1}^{3} \sum_{a=1}^{4} \sum_{k=1}^{29} R_{tak} F_{tak} - \sum_{t=1}^{3} \sum_{a=1}^{4} \sum_{k=1}^{29} C_{tak} W_{ak} - \sum_{a=1}^{4} \sum_{k=1}^{29} \sum_{t=1}^{3} X_{tak} <= 0$$

$$(3) \qquad \sum_{a=1}^{4} \sum_{k=1}^{29} W_{ak} <= B_k , \quad \text{for all k = 1, 2..., 29}$$

$$(4) \qquad \sum_{a=1}^{4} \sum_{k=1}^{29} F_{ak} = R$$

Here, L_{ak} is the price (hauling, loading and cost of litter) of applying litter in a^{th} crop acreage in k^{th} county (\$ per ton), W_{ak} is the tons of litter applied in a^{th} crop acreage in k^{th} county, p_t is the price in \$ per pound of t^{th} chemical nutrient, X_{akt} is pounds of t^{th} nutrient applied in a^{th} crop acreage in k^{th} county, T is the cost in dollars of transferring one ton of litter to one mile distance, D_{ij} is the distance in miles from i^{th} surplus county to the j^{th} deficit county, and Y_{ij} is the total tons of litter transported from i^{th} county to the j^{th} county.

In the first constraint equation, R_{tak} represents t^{th} nutrient requirement for a^{th} crop acreage in k^{th} county, F_{tak} is crop field where t^{th} nutrient applied in a^{th} crop acreage in k^{th} county, C_{tak} is the t^{th} nutrient content of the litter applied in a^{th} crop acreage in k^{th} county, W_{tak} is the amount of litter applied in a^{th} crop acreage in k^{th} county, X_{tak} is the amount of t^{th} nutrient applied in a^{th} crop acreage in k^{th} county from chemical fertilizer source. If $t = 2$ in this equation, it indicates phosphorus constraint and is an equality constraint. In the second constraint equation W_{ak} is the litter applied in a^{th} crop acreage in k^{th} county, and B_k is the total amount of broiler litter produced in k^{th} county. The third constrain says that all the crop land on four crops in each county should sum to the total crop land under four crop in the region. R is the total acreage of four crops considered in the region.

The objective function minimizes the total cost of meeting nutrient requirement in the 29 counties region which consists of minimizing the cost of chemical fertilizer, cost of broiler litter application, and cost of transportation. The hauling, loading, and spreading costs are built in the model. The first constraint equation mentions that all the nutrient requirement needs of the crop in the region have to be met from either broiler litter or chemical fertilizer. The second constraint equation says that the total litter used in surplus and deficit counties cannot exceed the total amount of litter production in the region.

Data

Data are collected from Alabama Agricultural Statistics Service (2000). Crop acreage under each crop in each county is obtained. Also, the quantity of estimated broiler litter production in each of these counties are calculated. Individual crop acreage and broiler production in each county are presented in Tables 2 and 3. Table 2 shows that five largest broiler producing counties are Blount, Cullman, DeKalb, Marshall, and Walker. The majority of the 29 counties considered here produce broiler litter that is sufficient to meet the nitrogen, phosphorus, and potash need of the respective county. Broiler litter production is calculated from broiler number in each county based on the formula provided by the AAES. For example, eight top counties considered in this study produced more than 1000 tons of phosphorus annually. Table 3 shows that the major crop producing counties are Lauderdale, Lawrence, Limestone, and Madison. Since the highest crop production and litter production counties are not the same, the litter transportation decision is mainly impacted by the distance between crop production and litter production counties among other things.

After the crop acreage and litter production in each county are accounted, these counties are divided into surplus and deficit counties. Surplus counties are those counties where the litter production exceeds the nutrient demand in the county. Deficit counties are those where the litter produced is not enough to meet the nutrient needs of the county. Surplus counties are indicated with a positive number and deficit counties are shown with a negative number in the last column of Table 4. The surplus and deficit counties obtained from Table 4 are rearranged and shown in Table 5. The calculation shows that there are 13 surplus counties and 16 deficit counties in the region. We developed transportation routes from each of these surplus counties to the nearby deficit counties. We did not consider all the routes from each surplus county to all the deficit counties because some of the deficit counties have comparative advantage in terms of distance benefit from surplus counties. Therefore, only the relevant routes are developed for the transportation. The surplus and deficit counties are shown in Figure 1. The transportation routes originating from each of the counties considered are shown in Table 6 and Figure 1. The unit cost for transportation is representative of the cost of transferring a ton of broiler litter to a distance of one mile. The cost is considered to be $0.10. The hauling and spreading costs are $3.5 per acre.

Results

There are 13 surplus and 16 deficit counties considered in this study. Total amount of litter production, litter used, total litter available for transportation out from the county, and total use percentage for all the 29 counties considered in this study are shown in Table 7. Most of the litter produced in the surplus counties is not fully utilized. Counties where the lowest amount of total litter utilized were Clay (22 percent), Cleburne (25 percent), Randolph (32 percent), and Blount (36 percent). The main reasons for this are high production and less crop acreage within the county and more costly for these counties to transfer litter out as there are other competing counties which could transfer litter with a lower cost. Still 14 of the 29 counties considered utilized their litter completely.

Table 8 shows the eight highest surplus counties, the total litter production in these counties, amount of total litter used, and the total amount transferred out of these counties. Table 9 shows the detail of how much of the litter is transferred out of each of the county in the optimal solution. The five most heavily surplus broiler litter producing counties are Blount, Cullman, DeKalb, Marshall, and Walker. Therefore, we discuss the details of the results from these five counties here.

Cullman is the highest litter producing county in the region. This county utilizes 60 percent of the total litter produced cumulatively from the in-county use and outside transfer. One-fourth of the utilized amount is applied in crop production area in the county whereas three-fourth of the amount is transferred to other counties. The main litter receiving counties from Cullman are Lawrence, Colbert, Lauderdale, and Limestone Counties. The reason most of the litter is transferred to Limestone County is its proximity to Cullman County compared to other counties, and also there is more crop acreage in Limestone County. Even though Colbert County is nearby Lauderdale County, litter was not transferred from Cullman to Colbert as Colbert could get litter from another surplus county for a cheaper cost (minimum distance).

DeKalb is the second largest county in terms of total broiler litter production in the study region as well as in Alabama. The total litter production in the county is 158,123 tons, out of which 44 percent is utilized combinedly on in-county and transfer to other counties. In-county use was 62 percent of the total litter utilized and 38 percent of the total litter used is transferred out of the county. Majority of the litter transferred from DeKalb County was to Jackson (37 percent of total transferred) and Cherokee counties (63 percent of total transferred). These two counties are within the distance of 21 and 25 miles from DeKalb County.

Marshall is the third largest county in terms of total broiler litter production in the region. The total litter production in Marshall county is 109,600 tons. Ninety percent of the litter produced is utilized as a source of plant nutrients either in-county or by transfer to other counties. Litter from this county is transferred out to Madison and Cherokee Counties, two of the adjacent high crop production counties.

Thirty-six percent of the total litter produced in Blount County was utilized in-county (56 percent). Forty-four percent of the litter produced is transferred to Talladega County. Talladega County is a deficit county and has more crop acreage and is nearer to Blount County than others. The major reason for this transfer of litter to another county is due to closer proximity and the highest acreage of cropland in the receiving counties.

Walker County is the fifth largest litter producing county in Alabama. Most of the crop acreage in this county is hay production. Walker County used only 35 percent of the total litter produced for in-county purpose and transferred the remaining amount to the adjacent counties such as Tuscaloosa and Shelby. Franklin, Morgan, and Winston were able to utilize all the litter produced in counties. Winston and Franklin transferred most of the litter to outside counties, whereas Morgan County utilized most of the litter within the county. Morgan County has high acreage of corn and hay production. Therefore, in-county utilization of the litter produced is an inexpensive alternative.

Generally, it is found that litter would be transferred based on the cost of transportation distance and the crop acreage in the receiving counties and their locations relative to the surplus counties. If the excess broiler litter producing counties are closely located to the deficit counties, litter was transferred to those counties. Because of the nature of the model as it is designed for the minimization of the total cost by the central planner, there was no priority to move the excess litter out from the most problematic counties (highly surplus counties) if it was not cheaper to do so.

Priority Based Model and Price Sensitivity

The above analysis on transportation of broiler litter from the broiler litter surplus counties to deficit counties showed that the cost minimizing central planner would not be able to completely solve the excess litter production in the surplus counties such as the top five litter surplus counties in the region.

The results showed 60 percent, 44 percent, 96 percent, 36 percent, and 75 percent of broiler litter produced in Cullman, DeKalb, Marshall, Blount, and Walker Counties were utilized. The least cost transportation model could not solve the problem of excess accumulation of broiler litter as it still leaves 63 percent of the total surplus broiler litter in three broiler producing counties.

In order to transfer significant amounts of surplus broiler litter from the major broiler producing counties, we developed a priority-based transportation model. The main objective of this model was to transfer broiler litter on a priority basis or on the basis of surplus amounts of broiler litter left after in-county use. This model was developed in such a way that first it transfers surplus amounts of the broiler litter from the most surplus broiler litter producing county followed by the second most surplus broiler litter producing counties and so on. Therefore, this model first transfers the surplus broiler litter from Cullman County. The surplus broiler litter from DeKalb, Marshall, and Blount Counties will only be transferred after completely utilizing all surplus broiler litter produced in Cullman County.

The results of the priority-based LP model are presented in Table 10. The results show that still the same 67 percent of the total surplus amount of broiler litter can be utilized under the priority system of broiler litter use. The LP transportation model without priority left 106,490 tons of broiler litter in Cullman County which constitutes 25 percent of total surplus broiler litter of the 29 counties. Analysis showed that the surplus broiler litter of Cullman County can be completely utilized if we transport and apply broiler litter on a priority basis with a penalty structure in the model. Penalty enforcement is imposed, accordingly litter is transferred only from Cullman County until the litter is completely transferred out. The optimal solution in this case resulted an additional cost of about $500,000 in comparison to the nonpriority optimization model.

The priority based model's first criteria, with emphasis on the highest litter surplus, failed to transfer (in Cullman County) significant amounts of broiler litter from the other major broiler producing counties such as Blount, DeKalb, and Marshall. In many cases, this model left more surplus broiler litter in surplus broiler litter producing counties. The optimization model without priority completely utilized surplus broiler litter of Morgan and Walker Counties, but transfer of surplus litter on priority basis left 19,226 and 36,311 tons of broiler litter in these two counties which may aggravate the problems related to broiler litter accumulation in these counties.

The priority-based optimization model transferred 227,026; 76,085; 26,804; and 15,965 tons of surplus broiler litter from the Cullman, Marshall, DeKalb, and Blount Counties. This model did not transfer surplus broiler litter from Calhoun, Franklin, Marion, Morgan, Pickens, and Winston Counties leaving high amount of surplus litter in these counties. This analysis did not give an acceptable solution to the problem of excess broiler litter accumulation in North Alabama even after using an alternative transfer approaches. This problem occurred because of a fixed amount of phosphorus requirement of the crops which does not allow excess application of broiler litter to cropland.

We examined the effect of fertilizer price change on total litter use and resulting effect in total cost for meeting the nutrient needs of the region. The result of this analysis is shown in Table 11. The amount of litter applied did not change until the price of chemical fertilizer increased up to 66 percent. When the price of chemical fertilizer increased from the current level, the total cost for meeting the nutrient need also increased proportionately. This is because litter is applied based on the phosphorus consistent rule and deficit nitrogen need has to be met from chemical fertilizers. When the price of chemical fertilizer increased, the total cost of meeting the nutrient need for the region went up. When the price of chemical fertilizer went below the current price, the amount of litter used did not change but the amount of total cost incurred by the central planner to meet the nutrient need decreased. The reason for this decrease is again because of the phosphorus binding constraint in the model.

Conclusions

The result of the analysis indicated that it is not possible to completely overcome the surplus litter production problem in North Alabama by limiting litter transfer within the 29 northernmost counties. However, it is possible to solve the surplus litter production problem in the most concentrated county with an additional cost of $0.5 million above the base solution.

Our study provided indication that it is possible to solve the excess litter problem to a certain extent if litter is transported from the concentrated broiler producing counties to the other counties in Alabama based on the phosphorus consistent rule. Our analysis assumes that litter can be transferred from one county to other counties like any market commodity. Of course, this requires the acceptance of litter by crop producers and assistance by the government to make litter an acceptable alternative for chemical fertilizers. Also, once the phosphorus indexing method which is currently in the process of being development by the Natural Resource Conservation Services (NRCS) gets disclosed, we can come up with precise spatial allocation rules for litter disposal. However, this study provides the evidence that litter can be transported economically out of the heavily broiler producing counties to minimize the environmental problems in the most serious problematic areas. This study did not consider the benefit of organic matter development that may be realized if broiler litter is used in the long run.

The caveat of the outcome is that we did not consider all the crop production counties in Alabama for litter transportation and utilization as crop nutrients. The cursory look at the litter production and crop acreage in the State does show that it may be possible to solve the litter problem completely. However, this requires that there must exist well operating market mechanisms for litter transportation, litter purchase, and responsible use of litter. The breakeven distance calculated in this study may not be enough to haul the litter profitably to crop production counties from the surplus production counties if a state-wide transportation model is considered. As such, there may be a concern that short-run solution of excessive litter production problem as suggested by the transportation model may not be the long-run optimal solution. However, the outcome of this model will be helpful to formulate the environmental policy tools such as zonal tax, zonal permit or zonal quota so that over production of litter can be avoided to protect our pristine water resources from phosphorus or nitrogen pollution (Innes; Goetz and Zilberman).

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

Crop	Year	Total Cost of Fertilizer ($/acre)	Additional Cost of Fertilizer and Broiler Litter ($)			Savings from Broiler Litter Use ($)	Breakeven Distance (Miles)
			N	K_2O	Litter		
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

Table 2. Total Number of Broilers and Available Amount of N, P_2O_5, and K_2O in the Twenty-nine Counties of North Alabama

Counties	Number of Broiler	Litter [1] production (Tons)	Available [2] N (Tons)	Available P205 (Tons)	Available K_20 (Tons)
Blount	59,105,000	99,296	2,309	2,234	1,489
Calhoun	13,189,000	22,158	515	499	332
Clay	15,928,000	26,759	622	602	401
Cherokee	5,590,000	9,391	218	211	141
Cleburne	16,404,000	27,559	641	620	413
Colbert	8,317,000	13,973	325	314	210
Cullman	160,264,000	269,244	6,260	6,058	4,039
DeKalb	94,121,000	158,123	3,676	3,558	2,372
Etowah	21,865,000	36,733	854	826	551
Fayette	2,126,000	3,572	83	80	54
Franklin	32,335,000	54,323	1,263	1,222	815
Jackson	22,596,000	37,961	883	854	569
Lamar	1,048,000	1,761	41	40	26
Lauderdale	2,689,000	4,518	105	102	68
Lawrence	25,424,000	42,712	993	961	641
Limestone	3,183,000	5,347	124	120	80
Madison	1,365,000	2,293	53	52	34
Marion	8,368,000	14,058	327	316	211
Marshall	65,238,000	109,600	2,548	2,466	1,644
Morgan	26,057,000	43,776	1,018	985	657
Pickens	23,915,000	40,177	934	904	603
Randolph	17,988,000	30,220	703	680	453
St. Clair	19,741,000	33,165	771	746	497
Talladega	8,509,000	14,295	332	322	214
Tuscaloosa	5,034,000	8,457	197	190	127
Walker	33,431,000	56,164	1,306	1,264	842
Winston	27,255,000	45,788	1,065	1,030	687

1. Broiler litter is calculated based on the conversion formula used by Mitchell
The formula was number of broiler*, live weight (4.8 lbs)*, amount of litter produced (0.7 lbs)
2. Available amount of N, P_20_5, and K_20 represents 75% of the total N, P_2O_5, and K_2O content in broiler litter

Table 3. Crop Acreage and Total Amount of Phosphorus Required by Corn, Cotton, Wheat, and Hay in the Twenty-nine counties of North Alabama

County	Corn (Acres)	Cotton (Acres)	Wheat (Acres)	Hay (Acres)	Total Phosphorus [1] Requirement (Tons)
Blount	4,000	1,000	0	14,000	450
Calhoun	3,700	890	0	9,800	337
Clay	0	0	0	5,300	133
Cherokee	4,100	18,300	0	5,800	593
Cleburne	1,000	0	0	5,400	155
Colbert	13,000	23,950	1,400	12,000	1,081
Cullman	5,400	1,140	1,000	29,500	898
DeKalb	16,000	0	3,300	25,200	1,049
Etowah	2,800	2,720	0	16,300	518
Fayette	3,300	2,360	0	5,700	256
Franklin	2,500	0	0	14,300	408
Jackson	28,000	0	4,100	15,700	1,076
Jefferson	0	0	0	7,000	175
Lamar	2,800	0	0	6,700	224
Lauderdale	10,000	18,820	6,100	19,900	1,257
Lawrence	8,900	33,600	3,400	17,500	1,390
Limestone	9,300	53,770	7,500	23,600	2,076
Madison	15,000	34,300	12,000	16,700	1,764
Marion	4,200	0	0	7,800	279
Marshall	9,900	0	0	18,200	653
Morgan	3,800	0	2,400	16,000	548
Pickens	4,500	2,010	0	9,000	355
Randolph	1,000	0	0	8,000	220
Shelby	700	4,010	0	10,500	357
St. Clair	0	0	0	12,100	303
Talladega	7,000	0	4,800	15,400	669
Tuscaloosa	6,500	3,740	1,000	8,500	447
Walker	0	0	0	13,300	333
Winston	0	0	0	8,200	205

1. Phosphorus requirement is calculated based on the recommendation by the Alabama Cooperative Extension System.

Table 4. Surplus and Deficit Amount of Phosphorus in the Twenty-nine Counties of North Alabama

County	Tons of Phosphorus[1] Required	Tons of Phosphorus Available	Surplus (+) /Deficit (-) amount of Phosphorus (Tons)
Blount	450	2,234	1,784
Calhoun	337	499	162
Clay	133	602	470
Cherokee	593	211	-382
Cleburne	155	620	465
Colbert	1,081	314	-767
Cullman	898	6,058	5,160
DeKalb	1,049	3,558	2,509
Etowah	518	826	309
Fayette	256	80	-175
Franklin	408	1,222	815
Jackson	1,076	854	-221
Jefferson	175	0	-175
Lamar	224	40	-184
Lauderdale	1,257	102	-1,155
Lawrence	1,390	961	-428
Limestone	2,076	120	-1,956
Madison	1,764	52	-1,712
Marion	279	316	37
Marshall	653	2,466	1,813
Morgan	548	985	437
Pickens	355	904	549
Randolph	220	680	460
Shelby	357	0	-357
St. Clair	303	746	444
Talladega	669	322	-347
Tuscaloosa	447	190	-257
Walker	333	1,264	931
Winston	205	1,030	825

1. Tons of phosphorus required covers the total amount of phosphorus required by corn, cotton, wheat, and hay.

Table 5. Surplus and Deficit Amount of Broiler Litter Based on the Phosphorus Requirement of Corn, Cotton, Wheat, and Hay in North Alabama

Litter Surplus Counties	Amount of Surplus litter (Tons)	Litter Deficit Counties	Amount of Deficit Litter (Tons)
Blount	78,503	Cherokee	16,795
Calhoun	7,117	Colbert	33,731
Clay	20,661	Fayette	7,715
Cleburne	20,463	Jackson	9,740
Cullman	227,026	Jefferson	7,700
DeKalb	110,386	Lamar	8,091
Etowah	13,578	Lauderdale	50,831
Franklin	35,850	Lawrence	18,853
Marion	1,642	Limestone	86,068
Marshall	79,772	Madison	75,324
Morgan	19,226	Shelby	15,695
Pickens	24,147	Talladega	15,284
Randolph	20,238	Tuscaloosa	11,309
St.Clair	19,523		
Walker	40,972		
Winston	36,311		

Table 6. Major Transportation Routes and Sub-Routes Developed to Transport Broiler Litter in Twenty-nine Counties of North Alabama

Transport Route Number	Approximate Distance (Miles)	From	To
Route 1	66	Blount	Limestone
1.1	41	Cullman	Lawrence
1.2	21	DeKalb	Jackson
1.3	19	Franklin	Colbert
1.4	35	Marshall	Madison
1.5	33	Morgan	Lawrence
1.6	52	Walker	Lawrence
1.7	25	Winston	Lawrence
Route 2	60	Blount	Madison
2.1	72	Cullman	Colbert
2.2	56	DeKalb	Limestone
2.3	37	Franklin	Lauderdale
2.4	58	Marshall	Limestone
2.5	35	Morgan	Limestone
2.6	74	Walker	Colbert
2.7	58	Winston	Lauderdale
Route 3	50	Blount	Talladega
3.1	78	Cullman	Lauderdale
3.2	25	DeKalb	Cherokee
3.3	37	Franklin	Lawrence
3.4	45	Marshall	Cherokee
3.5	62	Morgan	Lauderdale
3.6	43	Walker	Tuscaloosa
3.7	47	Winston	Colbert
Route 4	50	Cullman	Limestone
4.1	52	Franklin	Lamar
4.2	66	Morgan	Jefferson
4.3	56	Walker	Shelby
4.4	37	Winston	Fayette

Table 7. Total Amount of Broiler Litter Used based on the Phosphorus Intake Rate in the Twenty-nine Counties of North Alabama

County	Total Litter Production (Tons)	Total Litter Used (Tons)	Total Litter left (Tons)	Total Use (Percentage)
Blount	99,296	35,438	63,858	36%
Calhoun	22,158	14,969	7,189	68%
Clay	26,759	5,889	20,870	22%
Cherokee	9,391	9,391	0	100%
Cleburne	27,559	6,889	20,670	25%
Colbert	13,973	13,973	0	100%
Cullman	269,244	162,754	106,490	60%
DeKalb	158,123	69,786	88,337	44%
Etowah	36,733	23,018	13,715	63%
Fayette	3,572	3,572	0	100%
Franklin	54,323	54,323	0	100%
Jackson	37,961	37,961	0	100%
Lamar	1,761	1,761	0	100%
Lauderdale	4,518	4,518	0	100%
Lawrence	42,712	42,712	0	100%
Limestone	5,347	5,347	0	100%
Madison	2,293	2,293	0	100%
Marion	14,058	12,400	1,658	88%
Marshall	109,600	105,107	4,493	96%
Morgan	43,776	43,776	0	100%
Pickens	40,177	15,787	24,390	39%
Randolph	30,220	9,778	20,442	32%
St.Clair	33,165	13,444	19,721	41%
Talladega	14,295	14,295	0	100%
Tuscaloosa	8,457	8,457	0	100%
Walker	56,164	42,054	14,110	75%
Winston	45,788	45,788	0	100%

Table 8. Total Amount of In-county Boiler litter Used and Transferred from Eight Supply Counties to other Counties

County	Total Broiler Production (Tons)	Total Broiler Used (Tons)	Total In-county Use (Tons)	Total Amount Transferred (Tons)
Blount	99,296	35,438	19,998	15,440
Cullman	269,244	162,754	39,564	123,190
DeKalb	158,123	69,786	42,987	26,799
Franklin	54,323	54,323	18,111	36,212
Marshall	109,600	105,107	17,387	87,720
Morgan	43,776	43,776	35,998	7,778
Walker	56,164	42,054	14,784	27,270
Winston	45,788	45,788	9,114	36,674

Table 9. Amount of Broiler Litter Transferred Under Different Transportation Routes from Supply Counties to Demand Counties in North Alabama

Route Number	Supply Counties	Demand Counties	Distance (miles)	Litter Transferred (Tons)
1	Blount	Limestone	66	0
2	Blount	Madison	60	0
3	Blount	Talladega	50	15,440
1.1	Cullman	Lawrence	41	19,400
2.1	Cullman	Colbert	72	0
3.1	Cullman	Lauderdale	78	16,850
4	Cullman	Limestone	50	86,940
1.2	DeKalb	Jackson	21	9,839
2.2	DeKalb	Limestone	56	0
3.2	DeKalb	Cherokee	25	16,960
1.3	Franklin	Colbert	19	28,040
2.3	Franklin	Lauderdale	37	0
3.3	Franklin	Lawrence	37	0
4.1	Franklin	Lamar	52	8,172
1.4	Marshall	Madison	35	76,080
2.4	Marshall	Limestone	58	0
3.4	Marshall	Cherokee	45	11,640
1.5	Morgan	Lawrence	33	0
2.5	Morgan	Limestone	35	0
3.5	Morgan	Lauderdale	62	0
4.2	Morgan	Jefferson	66	7,778
1.6	Walker	Lawrence	52	0
2.6	Walker	Colbert	74	0
3.6	Walker	Tuscaloosa	43	11,420
4.3	Walker	Shelby	56	15,850
1.7	Winston	Lawrence	25	0
2.7	Winston	Lauderdale	58	22,850
3.7	Winston	Colbert	47	6,032
4.4	Winston	Fayette	37	7,792

Table 10. Total Amount of In-county Boiler litter Used and Transferred from Supply Counties to other Deficit Counties under the priority model

County	Total Broiler Production (Tons)	Transferred (Tons)	Surplus (Tons)
Blount	99,296	12570	65,933
Calhoun	22,158	0	7,117
Cullman	269,244	227,026	0
DeKalb	158,123	26,804	83,582
Franklin	54,323	0	35,850
Marion		0	1,642
Marshall	109,600	76,085	3,687
Morgan	43,776	0	19,226
Pickens		0	24,147
Walker	56,164	15,965	25,007
Winston	45,788	0	36,311

Table 11. Effects of Changes in the Price of Chemical Fertilizer on Total Cost, Total Amount of Boiler Litter Use and Total Amount of Broiler Litter Transfer

Scenarios	Total Cost (Thousand Dollars)	Total Applied (Thousand Tons)	Total Amount Transferred (Thousand Tons)
Price Increase			
Current price	21,913	789.6	360.7
25 percent	24,084	789.6	344.8
50 percent	25,202	789.6	344.8
66 percent	26,252	787.1	342.4
75 percent	26,837	783.5	338.8
100 percent	28,396	748.0	303.3
Price Decrease			
10 percent	21,255	789.6	344.8
25 percent	20,269	789.6	344.8
50 percent	18,624	789.6	344.8
75 percent	16,980	789.6	344.8

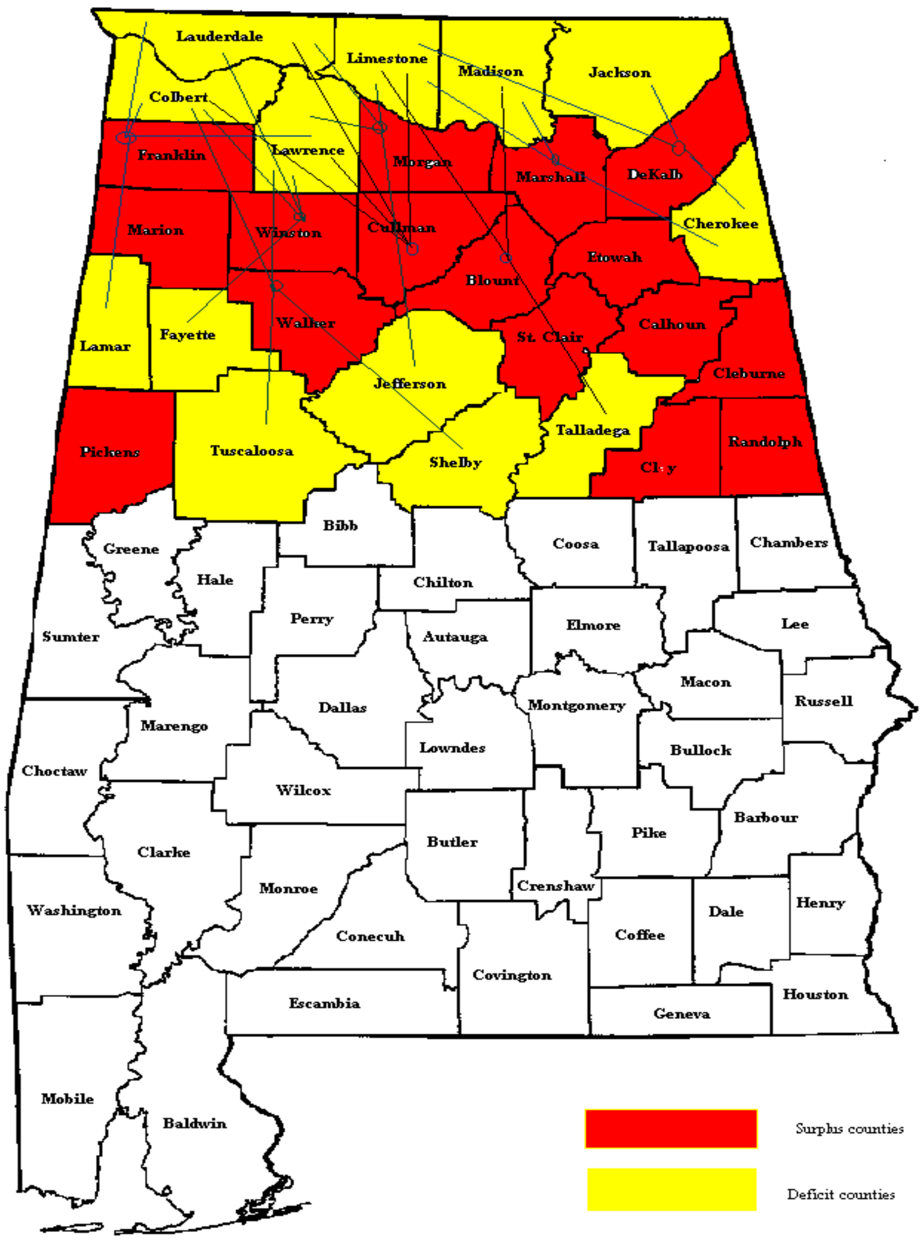

Figure 1. Surplus and deficit broiler production counties in North Alabama
(NOTE: Circle represents the origination of transportation routes from the selected surplus counties)