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Assessing the Market for Poultry Litter in Georgia: Are Subsidies Needed to Protect Water Quality?

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Concerns about nutrient loads into our waters have focused attention on poultry litter applications. Like many states with a large poultry industry, Georgia recently designed a subsidy program to facilitate the transportation of poultry litter out of vulnerable watersheds. This paper uses a transportation model to examine the necessity of a poultry litter subsidy to achieve water protection goals in Georgia. We also demonstrate the relationship between diesel and synthetic fertilizer prices and the value of poultry litter. Results suggest that a well-functioning market would be able to remove excess litter from vulnerable watersheds in the absence of a subsidy.

Key Words: fertilizer, phosphorous, poultry litter, subsidy, transportation model, water quality

JEL Classifications: Q12, Q13, Q25, Q53

Nutrient over-enrichment in watersheds throughout the United States threatens water quality and the use of water resources for drinking water, fishing, and recreation. Animal operations are one of several important contributors of nutrient loadings. In the Midwest, hog and cattle production are dominant sources; in the South and East, poultry production is especially important (Kellogg et al., 2000; Lander, Moffitt, and Alt, 1998).

To address water quality concerns associated with the use and disposal of poultry litter in vulnerable watersheds, several states have implemented incentives for transferring litter out of these watersheds. Alabama, Arkansas, Maryland, Oklahoma, Pennsylvania, Virginia, and West Virginia all have provided incentive payments for transporting chicken litter out of vulnerable watersheds.[1] The state of Georgia, the nation's leading broiler producer, also recently initiated a pilot program to facilitate poultry litter transport.

Like many states, Georgia's animal production is primarily concentrated in one region (the Piedmont), while major crop production is located in another (the Coastal Plain). Because poultry litter is bulky and heavy relative to

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[1] By vulnerable watersheds, we mean watersheds that are likely to experience water quality problems due to excess nutrient loads.

nutrient content, it has traditionally been applied to fields within the vicinity of the poultry grow-out operations. This has led to concerns about nutrient imbalances – when more nutrients are applied to an area than the plant matter (crops or other vegetation) can absorb – that can subsequently jeopardize water quality.

When considering environmental impacts of poultry litter application, the main concern is eutrophication or nutrient enrichment of surface water. Phosphorus (P) is the primary nutrient that causes fresh water eutrophication (Carpenter et al., 1998; Schindler, 1977). The risk of P from land-applied poultry litter reaching surface water is based on application rate, timing, and location (Lemunyon and Gilbert, 1993).

There is ample evidence that P concentrations in runoff increase as P application rates increase (Edwards and Daniels, 1992, 1993; Kleinman and Sharpley, 2003). Furthermore, as soil test P increases, P concentrations in runoff also increase (Edwards and Daniels, 1993; Pote et al., 1999).

From 2006–2008, U.S. Department of Agriculture Natural Resources Conservation Service (NRCS) implemented a pilot program in Georgia that subsidized the transport of poultry litter. Based on an assessment of county-level phosphorous balances, 17 counties in north Georgia were identified from which poultry litter could be transported at subsidized rates (Figure 1).[2] The pilot program paid recipients of the litter between $6 and $10 per ton. The pilot program contracted more than $600,000 in payments.

Although transporting poultry litter out of vulnerable watersheds is a laudable goal, is it necessary to subsidize litter transport in Georgia? Poultry litter is, after all, a valuable fertilizer, rich in phosphorous, nitrogen, potassium, and other micronutrients. It also serves to enhance soil organic matter and the ability of soils to retain moisture, and may lower soil acidity (Mokolobate and Haynes, 2002). The value of poultry litter as a substitute for inorganic fertilizers is intricately related to the price of those

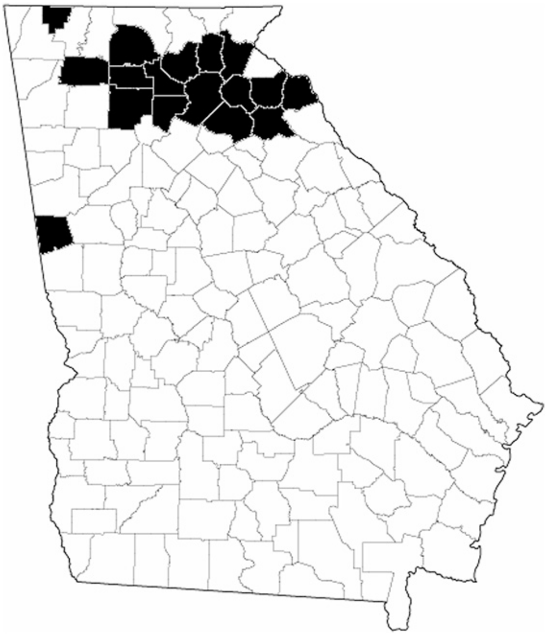

Figure 1. Location of Poultry Litter Removal Counties for Pilot Transfer Program in Georgia

fertilizers and the costs associated with litter transportation. Widely fluctuating oil prices over recent years have led to volatility in the prices of diesel fuel and fertilizers (Figure 2) which, in turn, suggest the value of poultry litter has also fluctuated.

Recent studies of poultry litter transport programs have found them to be effective in moving litter out of vulnerable watersheds (Carreira et al., 2007; Collins and Basden, 2006; Paudel, Adhikari, and Martin, 2004). Carreira et al. and Paudel, Adhikari, and Martin used linear programming models designed to minimize the cost of meeting crop nutrient requirements. Collins and Basden (2006) estimated the present value costs of nutrient applications, including litter, over an infinite horizon for tall grass hay land in West Virginia. They found the breakeven distance for transporting litter ranged from 120–260 miles, depending on litter cost, price, discount rate, and nitrogen efficiency assumptions.

Carreira et al. (2007) considered two modes of transportation – truck and barge – and two types of litter – baled and raw litter – for their analysis in Arkansas. They found that transporting baled litter by truck could lower nutrient

[2] For the purposes of our study, the watersheds that encompass these 17 counties are considered vulnerable watersheds.

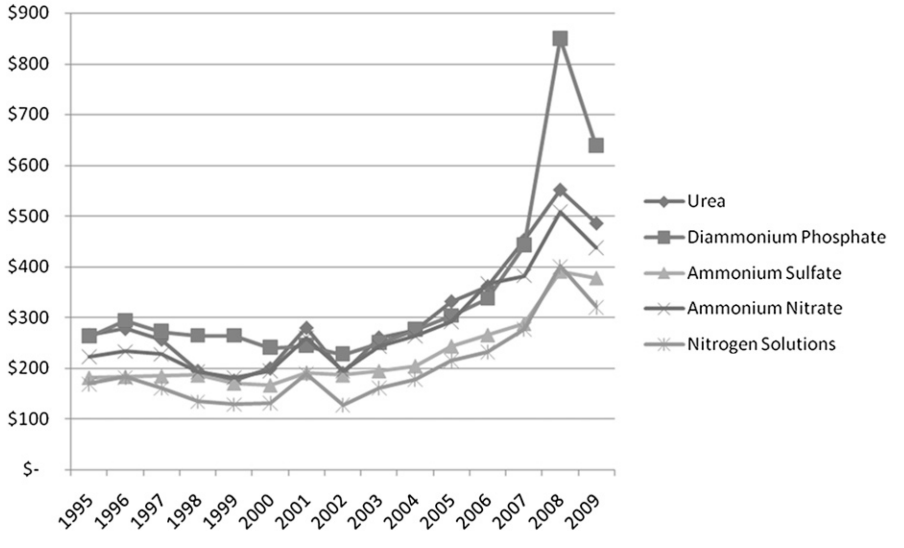

Figure 2. Commercial Fertilizer Prices 1995–2009 ($/ton)

costs by about $2.6 million. They concluded that public subsidies should not be necessary for a litter market to function in Arkansas.

Paudel, Adhikari, and Martin (2004) apply their model to 29 counties in northern Alabama, divided into "surplus" and "deficit" counties. Surplus counties are those that "exceed the cumulative nutrient demands for the four major crops. . .deficit counties are those in which litter production cannot meet the crops' nutrient demands" (p. 19). The cost of moving litter between surplus and deficit counties is incorporated into the model. The initial model solution left significant amounts of litter in surplus counties. In an attempt to address this, they solve a "priority model" in which surplus counties are ranked according to the tons of surplus litter. A penalty structure is used to manipulate the flow of litter out of surplus counties based on their ranking – all of the excess litter in the county with the largest surplus was forced to be removed before any litter in the county with the second largest surplus could be removed, and so on. Neither of these models succeeds in removing all of the excess litter from the surplus counties. This may be due to the geographic scope of the model.

In this paper, a transportation model is developed for Georgia to examine the ability of a well-functioning poultry litter market to redistribute poultry litter out of vulnerable watersheds and into areas with acceptable concentrations of soil phosphorous.[3] The model structure is similar to Paudel, Adhikari, and Martin (2004), but we specify the model for the entire state and use it to determine the need, or lack thereof, for a transportation subsidy given recent market fertilizer and diesel prices. We also identify how the market clearing price for poultry litter changes as the prices of fertilizer and diesel fuel change. Unlike Carreira et al. (2007), we do not consider baling litter prior to transport. We do, however, incorporate a potential liming effect into our model and examine the sensitivity of our results to the ability of poultry litter to serve as a substitute for lime.

Pilot Program for Litter Transport in Georgia

To address nutrient loading concerns in North Georgia watersheds, the U.S. Department of Agriculture Natural Resources Conservation Service in Georgia developed a pilot litter transfer

[3] We use the term "well-functioning litter market" to mean a market in which accurate information about buyers and sellers, market prices, and the nutrient content of litter is readily available at costs on par with the transaction costs associated with acquiring synthetic fertilizers.

incentive program in 2005. Implementation began in 2006. The pilot program had three objectives: (1) to create an incentive to distribute poultry litter to areas of the state that have historically not used poultry litter as a fertilizer, (2) to promote a long-term market for animal manure as a fertilizer around the state, and (3) to reduce over-application of poultry litter in areas where it has been traditionally over applied.

Farmers interested in using litter could apply for an incentive intended to offset transportation costs, but the litter had to originate in a "targeted removal" county and be applied in a "targeted application" county. The litter also had to be hauled by a Georgia licensed animal manure hauler. These counties were identified based on an assessment of the phosphorus balance in each county. Surplus counties were identified as removal counties, and other counties were application counties. Within each category, counties received a priority ranking, also based on the phosphorus balance.

The incentive payment was $10.00/ton, but an applicant could receive a higher ranking if willing to receive a lower payment rate (e.g., $6 or $8 per ton). Applications were ranked on several criteria, including: priority level of removal county, priority level of application county, willingness to accept a lower payment rate, receiving crop, P-index for receiving land, use of conservation tillage, availability of appropriate storage facilities, and litter application rate. The maximum incentive payment per farmer was $10,000.00 per year.

The receiver was required to have litter storage available that meets NRCS Waste Field Storage Standard, and litter application had to be based on the P-index (NRCS, 1994) and follow NRCS Nutrient Management Standards. No application sites with a P-index >75 were approved for litter application.

Methodology

The unit of analysis is the county. Poultry litter produced within each county is estimated based on county-level broiler production. Each county also has nutrient needs for the crops it grows. Seven crops are considered: corn, cotton, wheat, hay and pasture,[4] peanuts, and soybeans. The distance between two counties is measured as the linear distance from each county's centroid. The model presented below minimizes the cost of meeting the county's nutrient needs for the selected crops. The general form of the model is described in Equation (1). The symbols used in the model are defined in Table 1.

$$(1)\qquad \underset{F,BL}{Min} \sum_j \sum_i \sum_C \sum_F \begin{pmatrix} P_F * Fert_{F,C,i} + A_F * Fert_{F,C,i} + P_{BL} * BL_{C,i,j} \\ + A_{BL} * BL_{BL,C,i,j} + T_{BL,i,j} * L_{BL,,C,i,j} + P_{Lime} * Lime_{C,i} \end{pmatrix}$$

A county's crop nutrient needs are met by applying commercial fertilizers (F) and broiler litter (BL). Broiler litter can come from within the county itself, or be transported from another county. Application costs are based on the number of tons of fertilizer and broiler litter applied. Transportation costs are added for broiler litter hauled in from another county. These costs are figured on a per load basis, where a load is 25 tons. The cost of lime is also incorporated into the model.

Equation (1) is minimized subject to constraints 1.1 through 1.6.

$$(1.1)\qquad \sum_i \sum_C BL_{C,i,j} \le BL_{TOTAL,j} \forall j$$

$$(1.2)\qquad \sum_j \sum_F Fert_{F,C,i} N_F + BL_{C,i,j} * N_{BL} \ge N_{REQ,i,C} \forall i,C$$

[4] For counties located in the Coastal Plain, hay and pasture are assumed to be planted to Coastal Bermuda hay; counties outside the Coastal Plain are assumed to plant fescue clover on their hay and pasture land.

Table 1. Definitions and Symbols Used in Mathematical Programming Model

Symbol	Definition
P_F	Price per ton of commercial fertilizer F
$Fert_{F,C,i}$	Tons of commercial fertilizer F applied to crop C in county i
A_F	Application cost per ton of commercial fertilizer F
P_{BL}	Price per ton of broiler litter
$BL_{C,i,j}$	Tons of broiler litter applied to crop C in county i, received from county j
A_{BL}	Application cost per ton of broiler litter
$L_{BL,C,i,j}$	Loads of broiler litter received by county i from county j for crop C
$T_{BL,i,j}$	Cost of transporting a load of broiler litter from county i to county j
P_{Lime}	Price per ton of lime, including application cost
$Lime_{C,i}$	Tons of lime applied to crop C in county i
$BL_{TOTAL,j}$	Tons of broiler litter produced in county j
N_F	Proportion of fertilizer F that is nitrogen and available to the plant
N_{BL}	Proportion of broiler litter that is nitrogen and available to the plant
$N_{REQ,C,i}$	Tons of nitrogen required for crop C in county i
Ph_F	Proportion of fertilizer F that is phosphorous and available to the plant
Ph_{BL}	Proportion of broiler litter that is phosphorous and available to the plant
$Ph_{REQ,C,i}$	Tons of phosphorous required for crop C in county i
K_F	Proportion of fertilizer F that is potassium and available to the plant
K_{BL}	Proportion of broiler litter that is potassium and available to the plant
$K_{REQ,C,i}$	Tons of potassium required for crop C in county i
$Lime_{REQ,i,C}$	Tons of lime required for crop C in county i
$Dist_{i,j}$	Distance, in miles, between the geometric center of county i and the geometric center of county j
G_{BL}	Transportation cost per mile for a load of broiler litter

(1.3) $$\sum_j \sum_F Fert_{F,C,i} Ph_F + BL_{C,i,j} * Ph_{BL} = Ph_{REQ,i,C} \forall i,C$$

(1.4) $$\sum_j \sum_F Fert_{F,C,i} K_F + BL_{C,i,j} * K_{BL} \geq K_{REQ,i,C} \forall i,C$$

(1.5) $$Lime_{C,i} + BL_{C,i} \geq Lime_{REQ,i,C} \forall i,C$$

(1.6) $$T_{BL,i,j} = Dist_{i,j} * G_{BL} \forall i,j$$

(1.7) $$BL_{C,i,j}, Fert_{F,C,i}, Lime_{C,i} \geq 0 \forall C,F,i,j$$

The constraints represent physical relationships between the model variables, and can be interpreted as follows.

(1.1) The total amount of broiler litter transported out of a county cannot exceed the total amount of broiler litter produced in that county.

(1.2) The total amount of nitrogen applied to a crop in a given county, from all fertilizer sources, must meet, but can exceed, the total amount of nitrogen required by that crop in that county.

(1.3) The total amount of phosphorous applied to a crop in a given county, from all fertilizer sources, must exactly meet, and cannot exceed, the total amount of phosphorous required by that crop in that county.

(1.4) The total amount of potassium applied to a crop in a given county, from all fertilizer sources, must meet, but can exceed, the total amount of potassium required by that crop in that county.

(1.5) The total amount of lime applied to a crop in a given county, from all liming sources, must meet, but can exceed, the total amount of lime required by that crop in that county.

(1.6) The transportation costs per load of broiler litter between counties i and j are equal to the distance between the counties times the per mile cost of transporting a load of litter.[5]

[5] The model implicitly ignores the cost of transporting litter within a county. In other words, a county incurs no transportation costs for applying litter produced within the county.

(1.7) One cannot apply negative amounts of any fertilizer.

Setting the Parameter Values

The parameter values used in the model are presented in Table 2 for ease of reference. This section explains how those values were derived.

Broiler Litter Production

The annual amount of broiler litter produced in each county depends on the number of broilers raised per year. Each broiler generates 2.5 pounds of litter and grows to an average of 6.6 pounds (Vest, Merka, and Segars, 1994). To estimate the number of broilers produced in each county, the 2007 United States Department of Agriculture National Agricultural Statistics Service (NASS)

Table 2. Initial Parameter Values

Parameter	Values
Broiler Litter Production	2.5 lb litter/broiler
Pasture Land	2.6 acres/beef cow
	1.5 acres/stocker
	0.5 acres/dairy cow
Crop Land	Harvested acres as reported by NASS
Nitrogen Requirement	
Wheat	90 lb N/acre
Corn	180 lb N/acre up to 180 bushels/acre
	1.2 lb N/acre for each bushel over 180
Cotton	60 to 105 lb N/acre depending on production targets
Hay and Pasture	200 to 300 lb N/acre depending on location
Phosphorous Requirement	Depend on soil tests and equations listed in Appendix
Potassium Requirement	Depend on soil tests and equations listed in Appendix
Lime Requirement	Depend on soil tests
Poultry Litter Price	\$10/ton
Poultry Litter Application Cost	\$7/ton
Poultry Litter Transportation Cost/Mile	For each 25-ton load:
	\$0.98 + (price per gallon of diesel/5)
Commercial Fertilizer Application Cost	\$9.50/ton
Nitrogen Solution Cost	\$249/ton (2006), \$286/ton (2007),
	\$392/ton (2008), \$320/ton (2009)
Ammonium Nitrate Cost	\$390/ton (2006), \$425/ton (2007),
	\$543/ton (2008), \$438/ton (2009)
Ammonium Sulfate Cost	\$266/ton (2006), \$288/ton (2007),
	\$391/ton (2008), \$378/ton (2009)
Urea Cost	\$362/ton (2006), \$453/ton (2007),
	\$552/ton (2008), \$486/ton (2009)
Diammonium Phosphate	\$354/ton (2006), \$481/ton (2007),
	\$879/ton (2008), \$638/ton (2009)
Potassium Polyphosphate	\$318/ton (2006), \$358/ton (2007),
	\$650/ton (2008), \$482/ton (2009)
Potassium Chloride (Muriate)	\$294/ton (2006), \$309/ton (2007),
	\$524/ton (2008), \$853/ton (2009)
Broiler Litter Nutrient Content	
Nitrogen	64 lb N/ton, 60% available
Phosphorous	54 lb P_2O_5/ton, 90% P available
Potassium	48 lb K_2O/ton, 100% K available

P_2O_5 is Phosphorus pentoxide; K_2O is Potassium oxide.

estimates of the pounds of broilers produced are divided by 6.6 pounds/broiler. Multiplying by 2.5 pounds of litter/broiler results in the total pounds of litter, which is then converted to tons.

Crop Nutrient Requirements

The total requirement, in pounds, of each nutrient for each crop in each county depends on the number of acres grown and the per-acre crop nutrient requirement. County level crop acreages for all crops except pasture are set to the 2007 harvested acres reported by NASS, and can be found at http://www.georgiastats.uga.edu/crossection.html.

Because NASS does not report pasture acreage, it has to be calculated for each county. NASS does report county level beef cattle, stocker, and dairy cattle numbers, which can also be found at http://www.georgiastats.uga.edu/crossection.html. The acreage of pasture land in a county depends on the number of cows. Each beef cow is assumed to require 2.6 acres of pasture, while stockers and dairy cows are assumed to require 1.5 acres and 0.5 acres, respectively.

Nitrogen

Georgia Extension Service recommendations serve as the basis for setting the per acre nitrogen requirements for each crop. Peanuts and soybeans are nitrogen-fixing legumes that do not require additional nitrogen (N). As such, the nitrogen requirement for those crops is 0 pounds per acre. Wheat nitrogen requirements are assumed to be 90 pounds per acre for all counties. Corn and cotton nitrogen needs are based on production targets.

For corn, 180 pounds of N/acre are recommended for all production targets less than or equal to 180 bushels/acre. An additional 1.2 pounds N/acre is required for each bushel over 180. Production targets for each county are based on the county's 2007 average yield/acre, as reported by NASS.

For cotton, 60 pounds of N/acre are recommended for all the production targets less than 875 pounds lint per acre. Production targets between 875 and 1,125 pounds lint per acre require 75 pounds N/acre. Targets between 1,125 and 1,375 pounds lint/acre require 90 pounds of N, while targets above 1,375 pounds lint/acre require 105 pounds N/acre. As with corn, production targets for each county are based on the county's 2007 average yield/acre reported by NASS.

Nitrogen is recommended to be applied in two separate applications for all of the row crops. The first application, about one third of the total N recommended, should occur before or during planting; after plant emergence, the remaining two thirds of recommended N should be applied. Because poultry litter cannot be applied after plant emergence, the model accounts only for the first nitrogen application.

Hay and pasture nitrogen recommendations depend on the grass grown. For Coastal Plain counties growing Coastal Bermuda hay and pasture, the requirement is 300 pounds N/acre/year. Counties located outside the Coastal Plain growing fescue clover require 200 pounds of N/acre/year. All of the nitrogen for hay and pasture can come from broiler litter, and is applied after each cutting.

Phosphorous and Potassium

While the P-index was used to guide subsidized litter applications on specific fields in the Georgia Pilot Program, a county-level approach is used in our model. Phosphorous and potassium (K) recommendations depend on soil test P and K levels for all of the crops considered in the model. Results from soil tests conducted in 2006 and 2007 by the University of Georgia Soil Test Laboratory were averaged, by county and crop, to estimate the amount of phosphorous and potassium in a typical acre growing a given crop in a given county. If soil test levels exceed a threshold, no phosphorous (potassium) is recommended. Below that threshold, a quadratic equation is used to determine the phosphorous (potassium) application recommendation. Both the thresholds and the quadratic equations are crop specific and depend on whether the field is located in the Coastal Plain or not. For cotton, P and K recommendations also depend on target production levels. The threshold soil test P and K levels and the quadratic equations used to generate the P and K recommendations are presented in the appendix.

Two counties, Chattahoochee and Taliaferro, did not have soil test data for 2006 and 2007. To develop the P and K recommendations for these counties, the soil test levels of their contiguous neighbors were averaged.

Lime

Lime recommendations are dichotomous – either a field needs lime or does not. For those needing lime, an application rate of 0.75 tons of dolomitic lime per acre is used. It is further assumed that, pound for pound, poultry litter provides the same liming function as dolomitic lime; this assumption is later relaxed. To estimate the total amount of lime by crop and county, soil test results for 2006 and 2007 were used. The number of acres planted to a given crop was multiplied by the proportion of soil tests requiring lime in each county, and then multiplied by the application rate (0.75 tons/acre).

Fertilizer Considerations

Seven commercial fertilizers, plus broiler litter and dolomitic lime were incorporated into the model. The nitrogen fertilizers included ammonium nitrate, ammonium sulfate, nitrogen solutions, and urea. Phosphorous fertilizers were diammonium phosphate and potassium polyphosphate. The potassium fertilizer was potassium chloride (muriate).

Prices and Application Costs

Commercial fertilizer prices used in the model were those reported by NASS for the southeast region. Prices for 2006–2009 are presented in the appendix. The price of poultry litter was initially set to $10/ton. This is the median value from a survey of Georgia poultry producers, poultry litter users, and poultry litter transporters conducted in 2008.

Application costs were assumed to be $9.50/ton of commercial fertilizer. In the model, liquid fertilizers were able to be mixed, as were dry fertilizers. The cost of application included delivery. These decisions were based on a survey conducted during a series of poultry litter workshops in Georgia during 2007. The workshops were attended by more than 120 row crop and forage producers, poultry litter haulers and spreaders, and poultry producers.

Unlike commercial fertilizer, poultry litter had to be applied alone. The cost of applying poultry litter was set to $7.00/ton, the median value from the workshop survey. This application cost did not include delivery.

The cost of transporting a 25-ton load of litter has several components in addition to the price of diesel fuel. These include driver, truck, insurance, and maintenance costs, taxes, and a profit margin. Based on the workshop survey, on average these costs amount to $0.98/mile. A vehicle hauling a load of litter is assumed to get 5 miles per gallon. The total transportation costs per loaded mile in the model, then, are equal to $0.98 + price per gallon of diesel. While the model will accommodate partial loads, the transportation costs for a partial load are assumed to be the same as those for a full load. The distance between each county was measured in ARC GIS.

Broiler Litter Nutrient Content

Although the University of Georgia provides litter nutrient profiles as a service, those data are not retained. In lieu of data from Georgia, the average nutrient levels in broiler litter reported by North Carolina State University Department of Biological and Agricultural Engineering were used as estimates for nutrient content of broiler litter in Georgia. Each ton of broiler litter was assumed to contain 64 pounds of N, 54 pounds of diphosphorus pentoxide, and 48 pounds of potassium oxide, with 60%, 90%, and 100%, respectively, available to the plant. These values are similar to those used by Carreira et al. (2007) and are consistent with Georgia Cooperative Extension estimates (Kissel et al., 2008).

Model Scenarios

The model can examine a multitude of questions about the spatial demand for poultry litter as a fertilizer by adjusting the model parameters and constraints. Three scenarios were built and analyzed for this project.

Scenario I: No Transportation, P Equality

This scenario is designed to identify counties with excess poultry litter when nutrient application rates are based on phosphorous requirements. Transportation of litter out of a county is not allowed, which enables the model to calculate excess litter per county. Constraints (1.1) through (1.7) are set as described above. In particular, phosphorous applications must meet crop requirements, but cannot exceed them.

In addition to identifying counties with excess litter under a P-based fertilizer regime, Scenario I also calculates a shadow price for poultry litter for each county. Shadow prices represent the change in the objective function [Equation (1)] due to a marginal change in the limiting value of a constraint. The shadow price associated with constraint (1.1) in a given county represents how much the total fertilizer costs for the county would fall if the county had an additional ton of poultry litter. In other words, the shadow price on constraint (1.1) for county i represents the price producers in county i would be willing to pay for an additional ton of poultry litter. In counties with excess poultry litter, the shadow price would be zero – they already have more than they can use, so they would not be willing to pay for more. These counties are potential sellers of poultry litter. Counties with a non-zero shadow price are potential buyers.

Scenario II: No Transportation, P Inequality

Here, phosphorous applications must meet, but are allowed to exceed, crop requirements. This is accomplished by changing constraint (1.3) from an equality constraint to a greater than or equal to constraint, as in Equation (1.3a). Producers may choose the mix of commercial fertilizer and poultry litter that minimizes their nutrient costs without paying special attention to phosphorous.

$$(1.3a) \quad \sum_j \sum_F Fert_{F,C,i}Ph_F + BL_{C,i,j} * Ph_{BL} \geq Ph_{REQ,i,C} \forall i,C$$

Again, transportation of litter out of a county is not allowed.

Comparing Scenarios I and II generates an estimate of the cost of adhering to a P-based fertilizer regime. Scenario I solves equation 1 under a P-based regime, selecting the fertilizer mix for each crop in each county, and calculating the costs. Scenario II does the same thing, but relaxes the phosphorous constraint. Because poultry litter is the cheapest source of nitrogen, the model chooses it to meet the nitrogen requirement. Litter, however, also contains phosphorous.

Under Scenario I, producers must stop applying litter and switch to a commercial nitrogen fertilizer once the phosphorous requirement is met. Scenario II allows producers to continue to apply litter after the phosphorous requirement is met. Here, the model continues to choose poultry litter as a nitrogen source as long as the cost of acquiring and applying it is cheaper than other sources of nitrogen, regardless of the phosphorous issue.

Subtracting the total cost of meeting a county's nutrient requirements under Scenario II from the cost in Scenario I equals the cost of the P-based application requirement. That is, it is equal to the extra fertilizer costs producers incur when a P-based application rate is in effect.

There are several ways to interpret this value. It could be considered the cost to producers from historic over-application of phosphorous. Alternatively, it could be seen as the cost imposed on crop producers by P-based regulations. It can also be interpreted as the minimum compensation needed to persuade producers to abide by a P-based fertilizer regime. Under this last interpretation, a minimum selling price for poultry litter could be estimated by dividing the cost differential between Scenario I and II by the difference in excess litter between the two scenarios. This is represented by Equation (2).

$$(2) \quad MWTA_{BL,i} = \frac{(Cost_{i,I} - Cost_{i,II})}{((BL_{TOTAL,i} - \sum_C BL_{C,i,I}) - (BL_{TOTAL,i} - \sum_C BL_{C,i,II}))}$$

where $MWTA_{BL,i}$ is, for producers in county *i*, the minimum willingness to accept ($/ton) for a ton of broiler litter;

$Cost_{i,I}$ is the total cost of meeting fertilizer requirements in county *i* under Scenario I;
$Cost_{i,II}$ is the total cost of meeting fertilizer requirements in county *i* under Scenario II;
$BL_{TOTAL,i}$ is the total amount of broiler litter (tons) produced in county *i*;
$BL_{C,i,I}$ is the amount of broiler litter (tons) applied to crop *C* in county *i* under Scenario I;
$BL_{C,i,II}$ is the amount of broiler litter (tons) applied to crop *C* in county *i* under Scenario II.

This estimate can be generated for each county to illustrate the spatial dimension of the poultry litter market.

Scenario III: Transportation, P Equality

Scenario III opens up the market to litter transport, under a P-based fertilizer regime. That is, the counties with excess litter in Scenario I are now able to sell it, and the counties with non-zero shadow prices for litter are now able to buy it. The model tracks the exchange of litter between counties and identifies which counties, if any, continue to have excess litter after all exchanges are completed. It also identifies which counties continue to demand litter (those with a non-zero shadow price) after all exchanges have been completed.

If the 17 target counties from the Poultry Litter Pilot Program continue to have excess litter under current market conditions in Scenario III, that would suggest the need for financial support or regulatory mandates to remove it. In other words, under current market conditions, buyers would be unwilling to compensate the sellers in these 17 counties enough to cover their increased expenditures on commercial fertilizer.

However, if those counties are able to sell all of their excess litter in Scenario III, the case for financial support would be undermined. Rather, the preferred policy would be to encourage the application of a P-based fertilizer regime and facilitate the market exchange of litter without direct monetary incentives.

Results

County level broiler litter production is illustrated in Figure 3. It is worth noting that, while the bulk of broilers are grown in the Piedmont, there is considerable production throughout the state.

Cotton production is located primarily in the southwest of the state, an area with low levels of poultry production and generally low levels of soil phosphorous. Corn and wheat acreages drift a bit north of the cotton acres, with a fair amount of each located in the heavy poultry producing Piedmont counties. The hay and pasture acreages are dispersed fairly evenly throughout the state.

The initial results under Scenarios I, II, and III presented below are generated using a $10/ton price for litter, and the maximum diesel price recorded in Georgia between 2006 and 2009 ($4.71/gallon). These price parameters are then

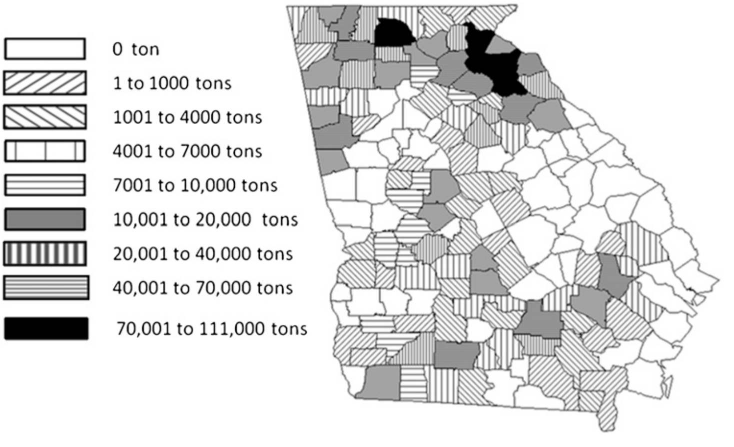

Figure 3. County Level Broiler Litter Production, 2007

adjusted to find the market clearing price of litter. The value of a potential liming effect from litter is addressed in the final section of the results.

Scenario I

As expected, the 17 target counties from the pilot program all had large amounts of excess litter under this scenario. There are, however, many counties with excess litter throughout the central and southeastern parts of the state. Figure 4 illustrates the excess litter in each county under 2008 fertilizer prices.

This scenario was run separately with fertilizer prices from 2006, 2007, 2008, and 2009. Over this period the price of nitrogen fertilizers rose by 49% on average, potassium chloride (muriate) rose by 78%, and the phosphate fertilizers more than doubled, rising by an average of 125%. These are strikingly high increases, and they have direct implications for the market value of litter. As explained above, the shadow price of broiler litter in the model reflects the marginal value of litter as a substitute for fertilizers. As such, it serves as an estimate of the maximum amount a producer would be willing to pay for a ton of litter, including transportation costs. Figures 5, 6, and 7 show the shadow prices for litter under fertilizer prices from 2006, 2007, and 2008, respectively.

What is important to note is that there is a spatial dimension to the shadow prices. The value of an additional ton of litter in a given county depends on the crops grown, the amount of litter produced in that county, and the price of other fertilizers. There is no single "value of litter." With 2006 fertilizer prices, the shadow prices ranged from \$11/ton to \$60/ton in the "buyer" counties – those without excess litter. With 2007 fertilizers prices the shadow prices rise to a range of \$21/ton to \$70/ton. When fertilizer prices are at 2008 levels, the shadow prices jump to between \$50/ton and \$100/ton.

Scenario II

In the 17 target counties the cost of meeting crop nutrient needs under Scenario I was \$31.2M. When the phosphorous constraint is relaxed in Scenario II the cost drops to \$18M. Table 3 shows how the \$13.2 million in additional costs are distributed across the 17 target counties. Also shown in the table, by county, is the difference in excess litter between Scenario I and Scenario II. This difference equals the amount of litter crop producers in the county would like to apply but are not able to because of the requirement of P-based application rates. Dividing the additional costs by the excess litter differential provides an estimate of the minimum price per ton that would be needed to entice the county to apply litter at P-based application rates and export the excess. This price does not include transportation costs. Rather, it is the price the litter suppliers would have to receive.

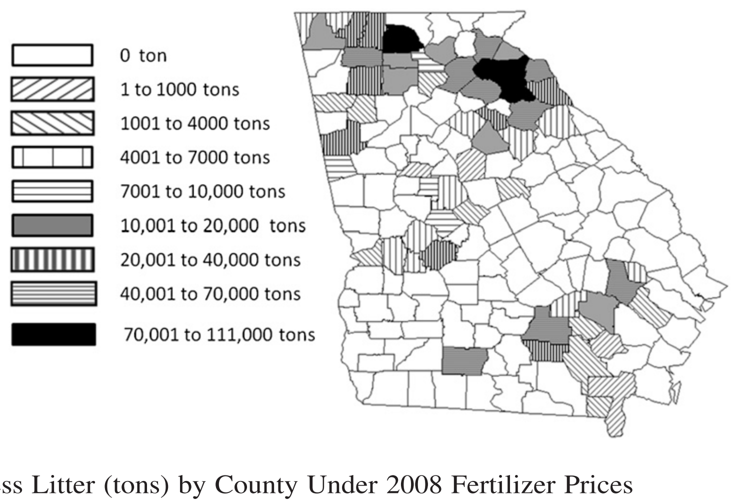

Figure 4. Excess Litter (tons) by County Under 2008 Fertilizer Prices

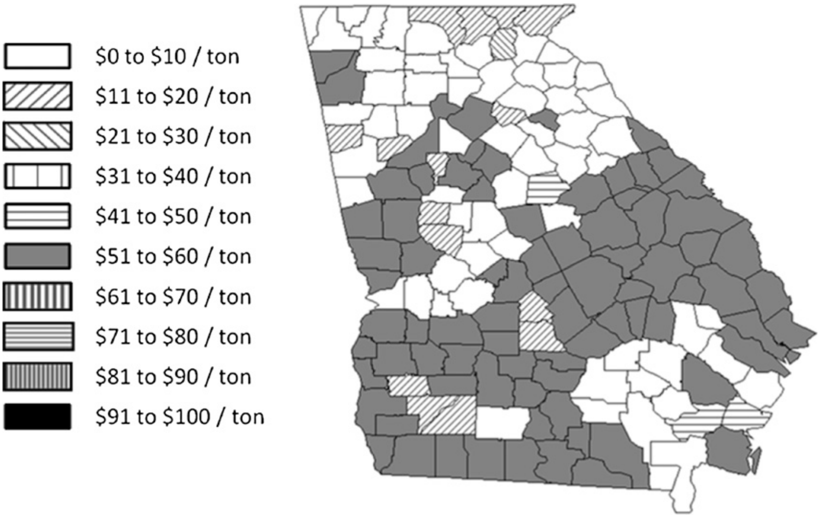

Figure 5. Shadow Price ($/ton) by County Under 2006 Fertilizer Prices

Scenario III

In this scenario litter is able to be transported out of the "seller" counties and into the "buyer" counties described above. Using 2008 fertilizer prices, a diesel price of $4.71/gallon, and $10/ton broiler litter, the solution to the model transports all excess litter from Scenario I out of the 17 target counties. This is not surprising, considering the range of 2008 shadow prices displayed in Figure 7 ($50/ton – $100/ton) is higher than the minimum price required by the target counties shown in Table 3 ($12/ton – $37/ton). The difference between the "seller" counties' asking price and the "buyer" counties' willingness to pay is more than enough to cover the transportation costs. In fact, with 2008 fertilizer prices the excess litter from all "seller" counties is bought, transported, and applied at P-based rates to crops in "buyer" counties. This suggests that a well-functioning litter market should be able to address the over-application of poultry litter in the target counties without public subsidies, given 2008 fertilizer prices and a $10/ton price of litter.

Sensitivity Analysis of Market Clearing Litter Price. Because litter is a substitute for commercial fertilizers, when fertilizer prices are high, the value of poultry litter should increase.

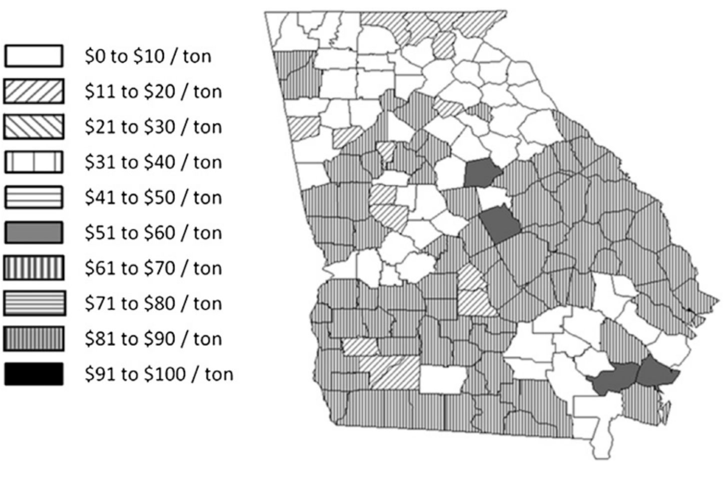

Figure 6. Shadow Price ($/ton) by County Under 2007 Fertilizer Prices

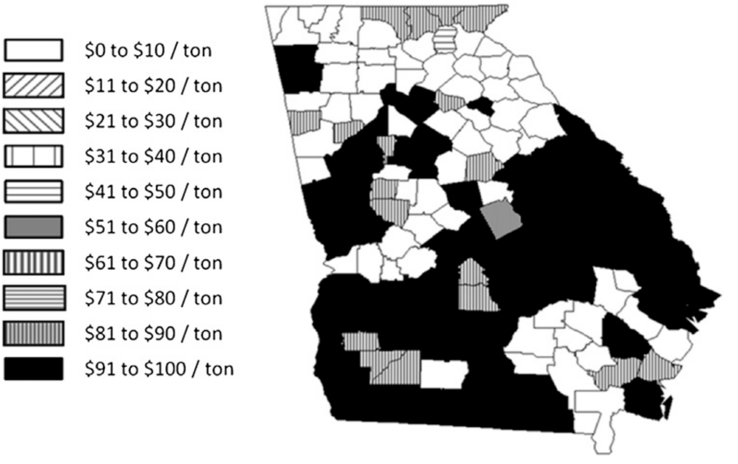

Figure 7. Shadow Price ($/ton) by County Under 2008 Fertilizer Prices

However, because diesel fuel is a complement to poultry litter, high fuel prices should depress the value of litter. Scenario III concluded that a litter market would remove all the excess litter from counties with excessive soil phosphorous levels when fertilizer prices are at their highest level (2008), even when diesel prices are also at their highest level. In fact, under these conditions, the price of litter could increase to $53/ton and the market would still clear. That is, all the excess litter would still be removed from high-phosphorous counties through mutually beneficial, voluntary transactions when litter costs up to $53/ton. The market-clearing price represents the marginal willingness to pay for the last ton of excess litter. It is the highest

Table 3. Costs to Producers and Excess Litter Generated by a P-Based Fertilizer Regime in Counties with Excessive Soil Phosphorous Levels

County	Additional Costs due to P-Based Applications ($)	Additional Excess Litter due to P-Based Applications (tons)	Minimum Selling Price for Additional Excess Litter ($/ton)
Banks	$1,388,656	59,476	$23.35
Catoosa	$109,412	6,345	$17.24
Cherokee	$174,201	13,617	$12.79
Dawson	$113,405	7,702	$14.72
Forsyth	$52,768	2,301	$22.93
Franklin	$1,536,054	88,736	$17.31
Gilmer	$489,284	34,562	$14.16
Gordon	$1,931,823	59,748	$32.33
Habersham	$1,098,747	58,702	$18.72
Hall	$754,421	62,501	$12.07
Hart	$2,066,346	63,207	$32.69
Heard	$357,626	9,868	$36.24
Jackson	$1,257,767	58,498	$21.50
Lumpkin	$206,828	10,325	$20.03
Madison	$1,506,752	89,901	$16.76
Pickens	$135,882	10,759	$12.63
			Weighted Average
Total	$13,044,090	625,489	$21.07

price per ton of litter that would achieve the policy goal of removing all of the excess litter from counties located in vulnerable watersheds.

As fertilizer and diesel prices change, however, so does the market-clearing price for litter. To analyze the effect of diesel and fertilizer prices on the market clearing price, Scenario III is run using four sets of fertilizer prices (2006 through 2009), and three different diesel prices – \$2.17/gallon (the average price in Georgia in February 2009), \$3.37/gallon (the average price in Georgia in February 2008), and \$4.71/gallon (historically the highest average price of diesel in the state of Georgia). Table 4 presents the results. The lowest market-clearing litter value (\$12/ton) occurs when diesel prices are at their highest, and fertilizer prices are at their lowest.

Sensitivity Analysis of Value of Liming Effect. In the analyses above, poultry litter was assumed, pound-for-pound, to have the same liming effect as dolomitic lime. Three alternative assumptions are analyzed. The first assumption is that poultry litter has no liming effect at all. The second assumption is that poultry litter has one quarter the liming effect of dolomitic lime; that is, four pounds of poultry litter provide the same liming effect as one pound of dolomitic lime. The final assumption analyzed is that poultry litter has one half the liming effect as dolomitic lime.

Under all three assumptions the market-clearing price for litter does not change. There is, however, an effect on the total cost of meeting crop nutrient and liming needs. If poultry litter does not have any liming effect, the cost of meeting crop needs with 2008 fertilizer prices, \$53.09 per ton litter, and \$4.71/gallon diesel is \$325.5 million. This cost drops to \$312.2 million, \$302.8 million, and \$294.8 million for quarter liming effect, half liming effect, and full liming effect, respectively. As the prices of litter and/or diesel fall, the value of the liming effect increases.

The magnitude of the liming effect also has an impact on the shadow price of litter when it is not transported between counties. For the counties that apply additional lime, the shadow price for litter is \$38.40 lower (the cost of a ton of dolomitic lime) when litter has no liming effect compared with the full liming effect. When litter is only half as effective as dolomitic lime, the shadow price of litter is \$19.20 higher than when there is no liming effect. Similarly, when litter is one fourth as effective as dolomitic lime, its shadow price is \$9.60 higher than when there is no liming effect.

Conclusions and Recommendations

Poultry litter is a valuable nutrient for crop production. Land application of poultry litter to meet plant nitrogen demand, however, can threaten water quality through phosphorous loadings. To prevent excessive litter application rates, many states have developed programs that subsidize the transportation of poultry litter out of vulnerable watersheds. Georgia has undertaken a pilot program to address this issue. Our analysis shows that a well-functioning market in Georgia would redirect poultry litter out of vulnerable watersheds without the need for a publicly funded transportation subsidy. This result is robust over a wide range of fertilizer prices and diesel fuel prices.

The model developed here is static and could be improved by incorporating dynamic soil nutrient effects and the value of important micronutrients such as calcium. More sophisticated means of estimating the amount of litter produced based on bird weight derived from a biological response function could also be incorporated (Willet et al., 2006). Another limitation of the study is the treatment of poultry litter as a perfect

Table 4. Maximum Market-Clearing Price of Litter

	Poultry Litter Market-Clearing Price (\$/ton)			
Diesel Price (\$/Gallon)	2006 Fertilizer Prices	2007 Fertilizer Prices	2008 Fertilizer Prices	2009 Fertilizer Prices
\$2.17	\$17.45	\$26.66	\$58.09	\$56.00
\$3.37	\$15.18	\$24.30	\$55.73	\$54.35
\$4.71	\$12.67	\$21.79	\$53.09	\$51.71

substitute for commercial fertilizers. In reality, litter is generally more difficult to handle than commercial fertilizers and may emit an offensive odor, which could reduce its price. Finally, some broiler grow out operations do not clean out all of their litter after every flock, as assumed here. Incorporating partial cleanout would affect the supply of litter, but not its demand. Such a scenario would strengthen our conclusions.

While our model results suggest a transportation subsidy is not needed to move excess litter out of vulnerable watersheds in Georgia, there is a role for the state to play. To establish a well-functioning market for poultry litter, the state could invest in lowering transaction costs within a litter market. This could be done by intensifying efforts to increase awareness and use of Georgia's poultry litter exchange website (www.galitter.org). The state could also consider hiring a "market-maker" to support this effort and to facilitate the distribution of information and the development of market relationships. On the demand side, increased extension efforts regarding the nutrient replacement value of litter would be helpful. Additionally, the development of water quality trading programs, like the one actively supporting poultry litter transfer in Pennsylvania (Baranyai and Bradley, 2008), could serve as an impetus for a litter market when phosphorus regulation is sufficiently strict.

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Appendix

The phosphorous and potassium recommendations are based on the following equations. The factors considered are soil nutrient content, crop, and whether the field is located in the Coastal Plain or Piedmont region of Georgia. Table A1 presents the P_2O_5 recommendation in pounds per acre. Table A2 presents the K_2O recommendations in pounds per acre.

Table A1. P_2O_5 Recommendations

Crop	Location	Threshold Soil Level (lbs P/acre)	Yield Target (lbs/acre)	Recommendation (lbs P_2O_5/acre)
Corn	Piedmont	75		$122 - 1.23P + 0.00574P^2$
Corn	Coastal Plain	100		$121 - 0.755P + 0.00147P^2$
Cotton	Piedmont	75	750	$129 - 3.074P + 0.01435P^2$
Cotton	Piedmont	75	1000	$146 - 3.228P + 0.01196P^2$
Cotton	Piedmont	75	1250	$163 - 3.383P + 0.00957P^2$
Cotton	Piedmont	75	1500	$173 - 3.383P + 0.00957P^2$
Cotton	Coastal Plain	100	750	$127 - 1.886P + 0.00366P^2$
Cotton	Coastal Plain	100	1000	$144 - 1.943P + 0.00183P^2$
Cotton	Coastal Plain	100	1250	$160 - 2P + 0P^2$
Cotton	Coastal Plain	100	1500	$170 - 2P + 0P^2$
Hay	Piedmont	75		$129 - 3.074P + 0.01435P^2$
Hay	Coastal Plain	100		$88 - 0.491P - 0.00293P^2$
Pasture	Piedmont	75		$103 - 2.459P + 0.01148P^2$
Pasture	Coastal Plain	100		$76 - 1.132P + 0.0022P^2$

P_2O_5 is Phosphorus pentoxide.

Table A2. K_2O Recommendations

Crop	Location	Threshold Soil Level (lbs K/acre)	Yield Target (lbs/acre)	Recommendation (lbs K_2O/acre)
Corn	Piedmont	75		$158 - 0.614K + 0.00107K^2$
Corn	Coastal Plain	100		$152 - 0.79K + 0.0019K^2$
Cotton	Piedmont	75	750	$126 - 0.439K + 0.00016K^2$
Cotton	Piedmont	75	1000	$133 - 0.373K - 0.00011K^2$
Cotton	Piedmont	75	1250	$158 - 0.46K - 0.00008K^2$
Cotton	Piedmont	75	1500	$165 - 0.394K - 0.00035K^2$
Cotton	Coastal Plain	100	750	$123 - 0.672K + 0.00054K^2$
Cotton	Coastal Plain	100	1000	$131 - 0.591K + 0.00002K^2$
Cotton	Coastal Plain	100	1250	$155 - 0.724K + 0.00012K^2$
Cotton	Coastal Plain	100	1500	$163 - 0.644K - 0.0004K^2$
Hay	Piedmont	75		$123 - 0.779K + 0.00083K^2$
Hay	Coastal Plain	100		$273 - 0.779K + 0.00083K^2$
Pasture	Piedmont	75		$98 - 0.622K + 0.00066K^2$
Pasture	Coastal Plain	100		$149 - 1.024K + 0.00215K^2$

K_2O is Potassium oxide.