The Feasibility of Poultry Litter Transportation from Environmentally Sensitive Areas to Delta Row Crop Production

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Arkansas ranks first in broiler production in the USA with more than a billion broilers and 1.5 million tons of litter produced in 1993. Transporting litter from western to eastern Arkansas can accomplish two goals: 1) avoid potential threat to clean water in western Arkansas and 2) can increase productivity of graded lands in the Delta. This paper examines the feasibility of litter transport from areas of high poultry concentrations to the Delta for use as a soil amendment. We establish the conditions for economical litter transport from source to destinations and determine the optimal rates of litter applications. The results suggest that it is economical to transport significant portions of litter.

Introduction

Non-point source pollution created by agriculture is one of the most damaging and widespread threats to a clean environment (National Research Council). Passage of the Clean Water Act 319 in 1987, highlighted a need and established funds to evaluate remedial strategies to minimize non-point source impacts of agricultural production. Disposal of animal wastes is often considered a key contributor to agricultural non-point pollution. The growth of the poultry industry in Arkansas has exploded in the past decade with an aim to meet the growing demand for poultry meat and egg products. As a result, approximately 1.5 million tons of poultry litter are produced each year in Arkansas. The growth of the poultry industry has concentrated litter production in some regions where nutrient applications may be in excess of plant uptake. This can lead to contamination of groundwater as well as surface water in the nearby areas (Govindasamy et al., 1994[a]; Govindasamy et al., 1994[b]; Decker, Griffee).

With the increased interest in the quality of ground and surface water, some questions being asked are whether it is more economical to keep the production radius of a broiler complex to a minimum and transport the excess litter out, or to expand the size of production radius so as to accommodate the litter locally. This study will examine the feasibility of transporting litter from surplus regions to areas less susceptible to nutrient loadings.

There is a growing interest in the feasibility of using poultry litter in the production of Delta row crops. In Arkansas, the poultry production is mostly concentrated in the northwest region whereas Delta row crop production is concentrated in the eastern region of the State. The transport of litter from areas of high poultry concentration to areas with lower potential for contamination may not only improve the surface and groundwater quality in the state, but may also enhance the productivity of disturbed soils in the Delta region.[1] The litter has been prove to increase the productivity of recently graded soils while it is less productive on ungraded soils (Rainey, Cochran and Miller; Miller, Wells and Norman). The market feasibility of transporting litter from the northwestern region to the eastern region depends on several factors. First, the farm level derived demand must be estimated to determine how much row crop

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[1] Phosphorus is considered to have the most potential for contamination in the Delta. However, Delta soils are borderline deficient in phosphorus so that poultry litter could be applied at recommended rates for decades before the P fixation capacity of these soils would be exceeded and significant environmental loadings would be observed (Govindasamy, 1994[b]). Therefore, the transportation of litter from northwest Arkansas will improve the overall water quality of the state.

farmers can afford to pay for the litter and still earn a profit. This will in turn depend on the yield response to the litter and market prices. Profitable use of the litter occurs at a rate where the value of the yield response equals the cost of the litter (i.e., VMP = MFC). The cost of the litter will be determined by the acquisition, transportation and handling costs. The transportation costs are a function of the mode of transportation, the distance between acquisition points and final destinations and the volume of material to be transported.

It is clear from the experimental results (Rainey, Cochran, and Miller; Miller, Wells, and Norman) that poultry litter does have desired yield responses on recently graded soils. Therefore, the more interesting question is not "whether to apply litter as a soil amendment in recently graded soils or not" but rather to ask what are the optimal application rates given the soil characteristics, transportation costs of poultry litter and the yield responses of crops. The past research has focused primarily on the optimal rates of litter applications for pasture lands in northwest Arkansas (Buchberger) which are used in this paper to determine the opportunity cost of litter. A poultry litter survey was conducted to document the Best Management Practices currently adopted in Washington county of Arkansas (Rutherford). The objectives of this paper are to: 1) establish the conditions for economical transport of litter from the poultry producing regions to the Delta; and 2) determine the optimal rates of litter application given the source and destination of litter, the derived demand for litter for crop production in the Delta region, and the cost of litter acquisition, transportation, spreading, and handling. We use a discontinuous non-linear optimization model to determine the optimal quantities of transport from source regions to destination regions as well as the optimal rates of litter application.

A survey (Rutherford) on poultry litter use was conducted in Northwest Arkansas to document the Best Management Practices (BMP). The survey results indicate that an average of 175.86 tons of litter is being produced per poultry farm in Washington county, Arkansas. The average number of houses per farm is 2.64 with a mode of 2. Most

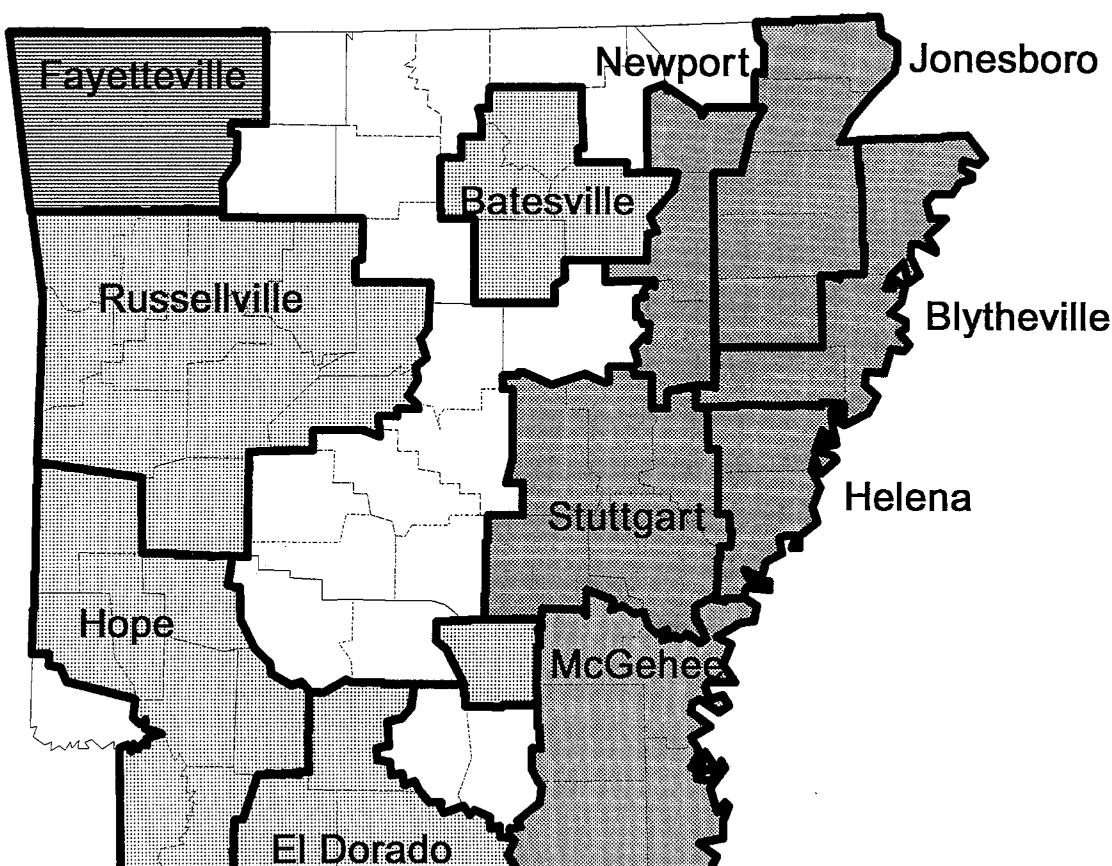

Figure 1. Litter Producing Regions and End Users

Table 1. Distance Between the Source Regions to Destinations (Miles)

	Sources				
Destination	Fayetteville	Batesville	Russellville	El Dorado	Hope
Stuttgart	252	108	127	126	157
Jonesboro	253	74	179	239	245
McGehee	297	188	183	99	146
Helena	305	135	191	191	222
Blytheville	306	127	230	285	298
Newport	220	29	133	204	183

growers (75%) produce 4.7 tons of litter or less per acre of pasture land managed. The BMP for litter rate on pasture indicates that litter application should not exceed 5 tons per acre per year with no more than 2.5 tons per acre when applications are split and no more than 4 tons per acre with single applications. The survey revealed that a local market for litter does exist. Also, the Delta region of the state could benefit greatly from the fertilizer value of litter on row crops.

The Model

A spatial equilibrium model was developed using the field experiments on yield response to poultry litter as a soil amendment on cotton, rice and soybeans. A regional discontinuous non-linear optimization model was developed using the input from budgeting analysis to assess the cost and returns of using poultry litter. The litter producing areas in Arkansas are divided into five source regions (Fayetteville, Batesville, Russellville, El Dorado and Hope). The destination areas for crop production are divided into six regions (Stuttgart, Jonesboro, McGehee, Helena, Blytheville, and Newport). Figure 1 provides the location of source and destination regions. Table 1 displays the distance between source and destination regions. The optional litter rates used are 1000, 1500, 2000, 2500, 3000, 3500, 4000, and 4500 pounds/acre. Two possible modes of transportation used to transport the litter are truck and rail. Poultry litter production from the source region, crop prices, area under crop production, and yields were estimated using Arkansas Agricultural Statistics. The area under graded soils was estimated through a phone survey (1993) with the county Soil Conservation Service (SCS) offices. The yields on graded soils compared to ungraded soils were estimated using the experimental data on crop responses to poultry litter. The cost of transportation through railroad was collected from Arkansas/Missouri Railroad Co. and through truck was estimated through a phone survey. The cost of transporting litter was approximately equivalent to the findings from Weaver and Souder.

The objective function maximizes the difference between increased revenue from the use of litter and the cost associated with the litter use. The increased revenue can be represented as

$$\sum_{d=1}^{6}\sum_{t=1}^{2}\sum_{r=1}^{8}\sum_{c=1}^{3} (\mathrm{YIELD}_{d,t,r,c} \;.\; \mathrm{PRICE}_c \;.\; \mathrm{ACRE}_{d,t,r,c}) \quad (1)$$

where

d	is six destination regions: Stuttgart, Jonesboro, McGehee, Helena, Blytheville, and Newport
t	is two soil types: graded and ungraded
r	is eight litter rates: 1000, 1500, 2000, 2500, 3000, 3500, 4000, 4500 pounds/acre
c	is three crops: rice, cotton and soybeans
$\mathrm{YIELD}_{d,t,r,c}$	is the increase in yield at each destination, each soil type, each rate of litter application and for each crop due to litter applications
PRICE_c	is the price of each crop
$\mathrm{ACRE}_{d,t,r,c}$	is the acres under each of the activity

The choice variable is the acreage under each of the activities given the yield response of each crop and the prices. The increased yields represented as $\mathrm{YIELD}_{d,t,r,c}$ were obtained from the field experimental results on rice, cotton and soybean for various rates of litter use. The cost associated with litter use can be subdivided into the following sections. The cost of transportation of litter from each source region to all destinations can be represented as

$$(2)\quad \sum_{s=1}^{5}\sum_{d=1}^{6}\sum_{m=1}^{2} (TCOST_{s,d,m} \cdot SUPPLY_{s,d,m} \cdot DISTANCE_{s,d})$$

where

s	represents five source regions: Fayetteville, Batesville, Russellville, El Dorado, and Hope
m	represents two modes of transportation: rail and truck
$TCOST_{s,d,m}$	represents the cost of transportation from each source to each destination through each mode of transportation in \$/ton/mile
$SUPPLY_{s,d,m}$	represents the total supply of litter from each source to each destination through each mode of transportaiton in tons
$DISTANCE_{s,d}$	represents the distance from each source to destinations in miles

The cost of transportation quotes from trucking companies were provided based on the size of the truck load per unit distance. As a result, the cost of transportation vary based on the mode of transportation such as rail and truck only. The discontinuous non-linear nature of the optimization model arises from the endogenous litter price. The model assumes that the price of litter is a function of the supply of litter. The value of the marginal product of litter as a fertilizer in local pasture is the opportunity cost for transported litter. To determine the opportunity cost of litter in the source region, a linear programming model was constructed with an objective to maximize the forage income given the litter availability and soil productivity constraints (Buchberger). The results from this linear programming model were used as an input to the discontinuous non-linear optimization model. A survey conducted by Rutherford indicates that about 80% of the litter is used as a fertilizer to the adjacent pasture production and 20% of the litter in the source region is sold to other producers in the state at an average price of \$5/ton. Litter will be transported to the Delta only if poultry growers can sell it for more than its value of marginal product as a forage fertilizer. The introduction of above mentioned constraints in the forage income maximization model leads to the following opportunity costs for litter use, based on its use as a fertilizer in pasture on the farm where it was produced. Twenty percent of the available litter can be sold at \$5/ton, 30% of the litter can be sold at \$13.81/ton and 50% of the litter can be sold at \$18.23/ton. That is, given the set up of profit maximization problem, when the litter is used for crop production in the Delta, the model would buy the first 20% of the available litter at \$5/ton. When the first 20% gets exhausted, the model would buy the next 30% of the litter at \$13.81/ton. Finally, when 50% of the available litter gets exhausted, the model would buy the rest of the 50% of the litter at \$18.23/ton. The opportunity costs of \$18.23 and \$13.81 are the shadow prices representing value of marginal product of litter in local forage production. Mathematically, the discontinuous non-linearity can be represented as

$$\begin{aligned}&LITTERCOST1 = \$5/ton\\ &\text{when}\quad SUPPLY < (0.2 * AVAILABLE)\\ (3)\quad &\text{provides SUPPLY 1}\end{aligned}$$

$$\begin{aligned}&LITTERCOST2 = \$13.81/ton\\ &\text{when}\quad (0.2 * AVAILABLE) < SUPPLY < (0.5 * AVAILABLE)\\ (4)\quad &\text{provides SUPPLY 2}\end{aligned}$$

$$\begin{aligned}&LITTERCOST3 = \$18.23/ton\\ &\text{when}\quad SUPPLY > (0.5 * AVAILABLE)\\ (5)\quad &\text{provides SUPPLY 3}\end{aligned}$$

Equation (3) implies that the 20% of the available litter can be bought at \$5/ton, equation (4) implies that 30% of the available litter can be bought at \$13.81/ton and equation (5) implies that 50% of the litter can be bought at \$18.23/ton. The cost of litter can be represented as

$$\begin{aligned}&\sum_{s=1}^{5}\sum_{d=1}^{6}\sum_{m=1}^{2} (SUPPLY1_{s,d,m} \cdot LITTERCOST1)\\ &+\sum_{s=1}^{5}\sum_{d=1}^{6}\sum_{m=1}^{2} (SUPPLY2_{s,d,m} \cdot LITTERCOST2)\\ (6)\quad &+\sum_{s=1}^{5}\sum_{d=1}^{6}\sum_{m=1}^{2} (SUPPLY3_{s,d,m} \cdot LITTERCOST3)\end{aligned}$$

where

$SUPPLY1_{s,d,m}$	represents the variable SUPPLY 1 at litter cost \$5/ton
$SUPPLY2_{s,d,m}$	represents the variable SUPPLY 2 at litter cost \$13.81/ton
$SUPPLY3_{s,d,m}$	represents the variable SUPPLY 3 at litter cost \$18.23/ton

The total supply of litter represented as $SUPPLY_{s,d,m}$ which is the sum of the choice variables SUPPLY 1, SUPPLY 2, and SUPPLY 3. That is,

$$SUPPLY_{s,d,m} = SUPPLY1_{s,d,m} + SUPPLY2_{s,d,m} + SUPPLY3_{s,d,m} \quad (7)$$

The cost of spreading litter can be represented as

$$\sum_{r=1}^{8}\left[\sum_{d=1}^{6}\sum_{t=1}^{2}\sum_{c=1}^{3}(ACRE_{d,t,r,c})\right] . SPREADCOST_r \quad (8)$$

where

$SPREADCOST_r$ represents the cost of spreading litter

The cost of spreading litter was based on Bosh and Napit. The variable cost of production was not incorporated into the model because the objective function maximizes the increased revenue due to litter applications but not the total revenue. The increased harvest costs due to increase in the yield was incorporated as

$$\sum_{d=1}^{6}\sum_{t=1}^{2}\sum_{t=1}^{8}\sum_{c=1}^{3}(YIELD_{d,t,r,c} \cdot HARVESTCOST_c) \quad (9)$$

where

$HARVESTCOST_c$ represents the harvest cost for each crop.

The increased harvest cost was calculated based on the Arkansas crop budget and production cost estimate. The harvest cost for rice includes custom hauling, drying, combine, for cotton includes row picker, cotton trailer and for soybean includes combine and custom haul. A litter availability constraint was introduced so that the total supply of litter is less than or equal to total litter production.

$$(10) \quad LITPROD_s \geq \sum_{d=1}^{6}\sum_{m=1}^{2} SUPPLY_{s,d,m}$$

where

$LITPROD_s$ represents the litter available at each source region.

The constraint on litter supply was introduced at each supply level to impose the discontinuous three stage litter price structure as follows.

$$(11) \quad \sum_{d=1}^{6}\sum_{m=1}^{2} SUPPLY1_{s,d,m} \leq LITPROD1_s$$

$$(12) \quad \sum_{d=1}^{6}\sum_{m=1}^{2} SUPPLY2_{s,d,m} \leq LITPROD2_s$$

$$(13) \quad \sum_{d=1}^{6}\sum_{m=1}^{2} SUPPLY3_{s,d,m} \leq LITPROD3_s$$

where

$$LITPROD_s = LITPROD1_s + LITPROD2_s + LITPROD3_s \quad (14)$$

The constraints (11), (12) and (13) were introduced to reflect the opportunity of litter use. These constraints facilitate application of the corresponding price for litter based on the quantity of litter supplied. The variables LITPROD1, LITPROD2 and LITPROD3 represent the amount of litter that is sold at an average price of \$5/ton (20% of the litter), \$13.81/ton (30% of the litter), and \$18.23/ton (50% of the litter) respectively. Also a litter use restriction was imposed in such a way that the litter supply must at least be equal to litter use in the destination regions. The litter use restriction can be represented as

$$\sum_{s=1}^{5}\sum_{m=1}^{2} SUPPLY_{s,d,m} \geq$$

$$(15) \quad \sum_{t=1}^{2}\sum_{r=1}^{8}\sum_{c=1}^{3} ACRE_{d,t,r,c} \cdot LITTERRATE_r$$

where

$LITTERRATE_r$ represents the rate of litter application for each of the eight treatments r.

Finally, a crop acreage constraint was introduced as follows

$$(16) \quad \sum_{r=1}^{8} ACRE_{d,t,r,c} \leq AREA_{d,t,c}$$

where

$AREA_{d,t,c}$ represents the acres available for crop production

This constraint limits the area under cultivation to be less than available. In summary, the objective function maximizes the increased revenue from litter use given in equation (1) net of the cost of litter use given in equations (2), (6), (8) and (9), subject to the constraints such as litter supply restrictions, stepwise endogenous price constraints, cost of litter use constraints and the acreage constraints. The primary choice variable is the acreage under each crop at each rate of litter application. The amount of litter transported is a function of the crop grown and the rate of litter application. Optimal acreage under each crop with optimal rate of litter application drives the optimal quantity of litter transport. As a result, the model provides the optimal quantity of litter transported under crop price assumptions, yield responses and litter transportation and acquisition costs.

A sensitivity analysis was conducted in addition to the base scenario which assumes that the cost of truck transportation is $0.10/ton/mile, cost of handling litter is $11.42/ton and the cost of spreading is $3.67/acre (Bosh and Napit).[2] The base crop prices used are three year state averages of $0.071/ pound of rice, $0.606/pound of cotton and $5.858/ bu. of soybeans (Arkansas Agricultural Statistics). The litter transportation cost sensitivity scenario analyzes the robustness of the optimal solutions to changes in the cost of transporting the poultry litter. The crop prices sensitivity scenario analyzes the impact of changes in the crop prices on the optimal solutions. The model was constructed and solved using General Algebraic Modeling System (GAMS) (Brooke et al.).

[2] The optimal solution indicates that the rail transport is uneconomical due to higher cost of transportation given the source regions and destination regions.

Results

Base Scenario:

Table 2 provides the optimal quantities of litter transportation from each of the five source regions to each of the six destinations. It is optimal to transport the entire litter production from all the source regions except Fayetteville. That is, only about 66% of the litter is transported with an opportunity cost of $18.13/ton of litter. Primarily, two reasons can be attributed towards this limited transportation of litter such as the high opportunity cost of litter use in the local pasture production for the 50% of litter, and the highest transportation distance from Fayetteville to any destination regions. As the opportunity cost of litter declines, the optimal quantity of litter transported from the source regions to destinations increases. That is, when the price of litter in the local market declines, it is more profitable to export the litter to Delta.

Table 3 provides the optimal choice of crop mix, graded or ungraded soil type, rate of litter application and the acreage for the base scenario. The optimal solution indicates that truck transportation is favorable to haul the litter than rail. As expected, it is optimal to apply litter for graded soils irrespective of the crops grown, given the distance between the source and destinations. The optimal application rates are about 3000 pounds/acre for rice, 4000 pounds/acre for cotton and 2000 pounds/acre for soybeans. Depending on yield response to litter applications and distance from the source regions, it is sometimes optimal to apply 1000 pounds of litter per ungraded acre of rice.

Transportation Cost Sensitivity Scenario:

In this scenario, the impact of changes in transportation cost is evaluated. From the base scenario value $.10/mile/ton, the transportation costs were increased to $.15/mile/ton and $.20/mile/ton. The results are presented in Tables 4 and 5. As expected, the increased transportation costs decreased the optimal amount of litter to transport. With a transportation cost of $0.15/mile/ton of litter and an opportunity cost of $18.23/ton of litter, it is optimal to transport the entire litter only from Batesville, Russellville, and El Dorado. The results indicate that it is non-optimal to transport any litter not only from Fayetteville but also from Hope. As a result, the unused litter with an opportunity cost of $18.23/ton of litter increased from 34% to 61%. However, at an opportunity cost of $13.81/ton of litter, it is optimal to transport the

Table 2. Base Scenario Results from Discontinuous Non-linear Optimization[1]

Source[2]/Destination/Mode of Transport of Litter	Optimal Quantity (million pounds)	% of Available Supply
Step Function 1 (Supply 1): Litter Opportunity Cost: $5/ton		
1) Fayetteville.Jonesboro.Truck	127	100
2) Batesville.Jonesboro.Truck	30	100
3) Russellville.Newport.Truck	94	100
4) El Dorado.McGehee.Truck	25	100
5) Hope.Stuttgart.Truck	101	100
Step Function 2 (Supply 2): Litter Opportunity Cost: $13.81/ton		
1) Fayetteville.Jonesboro.Truck	37	19
2) Batesville.Jonesboro.Truck	39	88
3) Batesville.Newport.Truck	6	12
4) Russellville.Stuttgart.Truck	71	50
5) Russellville.Helena.Truck	70	50
6) El Dorado.McGehee.Truck	37	100
7) Hope.McGehee.Truck	151	100
Step Function 3 (Supply 3): Litter Opportunity Cost: $18.23/ton		
1) Batesville.Newport.Truck	74	100
2) Russellville.Blytheville.Truck	104	44
3) Russellville.Newport.Truck	131	56
4) El Dorado.McGehee.Truck	61	100
5) Hope.Stuttgart.Truck	232	92
6) Hope.McGehee.Truck	21	8

[1]Truck transportation cost at $0.10/ton/mile, crop prices at $0.071/lb, $0.606/lb, and $5.858/bu. for rice, cotton and soybean, respectively.
[2]Litter availability (million pounds) at each of the source regions are: Fayetteville 634, Batesville 149, Russellville 470, El Dorado 123, and Hope 505.

entire litter from all source regions except Fayetteville because the opportunity cost of litter drops from $18.23 to $13.81/ton of litter. Although, the same effect has been observed in the base scenario, in this scenario, the unused litter with an opportunity cost $13.81 increased from 36% to 44%. The unused litter with an opportunity cost of $18.23/ton increased from 34% in the base scenario to 76% with a transport cost of $0.20/mile/ton of litter. Also with an opportunity cost of $13.81/ton of litter, the unused litter increased from 36% to 80% with a transport cost of $0.20/mile/ton. In summary, either a decrease in the transportation cost or a decrease in the opportunity cost of litter use in the local market have the same effect of increasing the optimal litter transported.

Output Price Sensitivity Scenario:

In this scenario, the impact of changes in the crop prices on the optimal solutions is analyzed. Specifically, the crop prices were increased by 20%

Table 3. Optimal Choice of Crop, Soil, Litter Rate and Acreage for Base Scenario

Destination/Crop/ Litter Rate (lbs/A)	Ungraded Soil Acreage	Application Rate (lbs/A)	Graded Soil Acreage	Application Rate (lbs/A)
1) Stuttgart.Rice.	329570	1000	11600	3500
2) Stuttgart.Cotton.	0	0	3500	4000
3) Stuttgart.Soybean.	0	0	6500	3000
4) Jonesboro.Rice.	0	0	50500	3500
5) Jonesboro.Cotton.	0	0	4000	4000
6) Jonesboro.Soybean.	0	0	19500	2000
7) McGehee.Rice.	127300	1000	28000	3500
8) McGehee.Cotton.	16869	1500	11000	4000
9) Helena.Rice.	0	0	20000	3500
10) Blytheville.Rice.	0	0	11550	3500
11) Blytheville.Cotton.	0	0	17500	3500
12) Blytheville.Soybean.	0	0	1250	2000
13) Newport.Rice.	163100	1000	37800	3500
14) Newport.Soybean.	0	0	4700	2000

Table 4. Sensitivity Scenario Results from Discontinuous Non-linear Optimization[1]

Source/Destination/Mode of litter transport (million pounds)	Crop Prices		Transport Cost	
	20% Up	20% Down	$0.15/t/m	$0.20/t/m
Step Function 1 (Supply 1): Litter Opportunity Cost: $5/ton				
1) Fayetteville.Jonesboro.Truck	127	127	48	0
2) Fayetteville. Blytheville.Truck	0	0	79	0
3) Batesville.Jonesboro.Truck	0	0	30	0
4) Batesville.Blytheville.Truck	0	30	0	0
5) Batesville.Newport.Truck	30	30	0	30
6) Russellville.Stuttgart.Truck	0	11	0	0
7) Russellville.Jonesboro	0	0	34	0
8) Russellville.Helena.Truck	0	40	60	0
9) Russellville.Newport.Truck	94	0	0	94
10) Russellville.Blytheville.Truck	0	43	0	0
11) El Dorado.McGehee.Truck	25	25	25	25
12) Hope.McGehee.Truck	31	81	0	0
13) Hope.Stuttgart.Truck	0	0	0	71
14) Hope.Helena.Truck	70	20	0	11
Step Function 2 (Supply 2): Litter Opportunity Cost: $13.81/ton				
1) Fayetteville.Jonesboro.Truck	49	0	0	0
2) Fayetteville.Blytheville.Truck	113	0	0	0
3) Fayetteville.Newport.Truck	28	0	0	0
4) Batesville.Newport.Truck	44	0	0	0
5) Batesville.Jonesboro.Truck	0	19	44	0
6) Batesville.Blytheville.Truck	0	25	0	44
7) Russellville.Stuttgart.Truck	30	21	122	0
8) Russellville.Newport.Truck	111	120	0	0
9) Russellville.Jonesboro.Truck	0	0	0	141
10) Russellville.Blytheville.Truck	0	0	19	0
11) El Dorado.McGehee.Truck	37	37	37	37
12) Hope.Stuttgart.Truck	0	30	106	0
13) Hope.McGehee.Truck	151	0	46	0
Step Function 3 (Supply 3): Litter Opportunity Cost: $18.23/ton				
1) Fayetteville.Jonesboro.Truck	317	0	0	0
2) Batesville.Jonesboro.Truck	74	74	74	54
3) Batesville.Newport.Truck	0	0	0	18
4) Russellville.Stuttgart.Truck	235	0	94	0
5) Russellville.Helena.Truck	0	0	0	49
6) Russellville.Newport.Truck	0	0	142	0
7) Russellville.Blytheville.Truck	0	0	0	45
8) El Dorado.McGehee.Truck	61	0	61	61
9) Hope.Stuttgart.Truck	138	0	0	0
10) Hope.McGehee.Truck	114	0	0	0

[1]The base scenario uses truck transportation cost at $0.10/ton/mile, crop prices at $0.071/lb, $0.606/lb, and $5.858/bu for rice, cotton, and soybeans, respectively.

and decreased by 20% compared to the base prices. The results are presented in Tables 5 and 6. The impact of increased crop prices was similar to that of decreased transportation costs. Unlike the base scenario, with 20% increase in crop prices, the optimal solution indicates that the entire litter production from all the source regions should be transported to the destinations. The intuition behind this result is that higher crop prices have shifted the derived demand for litter upward. The optimal rates of litter application thus have increased from 3000 pounds, 4000 pounds, and 2000 pounds/acre to 3500 pounds, 4000 pounds and 2500 pounds/acre of rice, cotton and soybeans, respectively. With a 20% decrease in crop prices, it is optimal to transport the entire litter only from Batesville to destinations at an opportunity cost of $18.23/ton of litter. That is, the unused litter increases from 36% in the case of base scenario to 92% with 20% decrease in crop prices. The impact of 20% decrease in crop prices seems to have a bigger impact on the optimal quantity of litter transported than the increase in the transportation cost to $0.20/mile/ton. As a result, the optimal rates of litter application also decreases to about 3000 pounds/acre of cotton and 1500 pounds/acre of soybean. With a 20% decrease in crop prices, the optimal solution indicates that none of the ungraded soils should be amended with poultry litter. The intuition behind this solution is that the value

Table 5. Optimal Choice of Crop, Soil, Litter Rate & Acreage for Sensitivity Scenario

Transportation Cost	$0.15/ton/mile		$0.20/ton/mile	
Destination/Crop/ Litter Rate (lbs)	Acreage Ungraded	Acreage[1] Graded	Acreage Ungraded	Acreage Graded
1) Stuttgart.Rice. (1000) 3500	250410	11600	0	11600
2) Stuttgart.Cotton.4000	0	3500	0	3500
3) Stuttgart.Soybean.2500	0	6500	0	6500
4) Jonesboro.Rice.3500	0	50500	0	0
5) Jonesboro.Rice.3000	0	0	0	50500
6) Jonesboro.Cotton.3500	0	4000	0	4000
7) Jonesboro.Soybean.2000	0	19500	0	0
8) Jonesboro.Soybean.1500	0	0	0	19500
9) McGehee.Rice. (1000) 3500	127300	28000	0	28000
10) McGehee.Cotton.4000	0	11000	0	11000
11) Helena.Rice.3000	0	20000	0	20000
12) Blytheville.Rice.3000	0	11550	0	0
13) Blytheville.Rice.2500	0	0	0	11550
14) Blytheville.Cotton.3500	0	17500	0	17500
15) Blytheville.Soybean.1500	0	1250	0	0
16) Blytheville.Soybean.1000	0	0	0	1250
17) Newport.Rice.3500	0	37800	0	37800
18) Newport.Soybean.2000	0	4700	0	4700

[1]Figures in parenthesis are the optimal rates of litter application to ungraded soils whereas figures outside the parenthesis are the optimal rates of litter application to graded soils.

Table 6. Optimal Choice of Crop, Soil, Litter Rate & Average for Sensitivity Scenario

Change in Crop Prices	20% Increase		20% Decrease	
Destination/Crop/ Litter Rate (lbs/A)	Optimal Acreage Ungraded	Optimal[1] Acreage Graded	Optimal Acreage Ungraded	Optimal Acreage Graded
1) Stuttgart.Rice. (1000) 3500[2]	329570	11600	0	0
2) Stuttgart.Rice.3000	0	0	0	11600
3) Stuttgart.Cotton.4000	0	3500	0	3500
4) Stuttgart.Soybean.3000	0	6500	0	0
5) Stuttgart.Soybean.2000	0	0	0	6500
6) Jonesboro.Rice. (1000) 3500	324430	50500	0	50500
7) Jonesboro.Cotton.4500	0	4000	0	0
8) Jonesboro.Cotton.3500	0	0	0	4000
9) Jonesboro.Soybean.2500	0	19500	0	0
10) Jonesboro.Soybean.1500	0	0	0	19500
11) McGehee.Rice. (1000) 3500	127300	28000	0	28000
12) McGehee.Cotton. (1500) 4000	99926	11000	0	11000
13) Helena.Rice.3500	0	20000	0	0
14) Helena.Rice.3000	0	0	0	20000
15) Blytheville.Rice.3500	0	11550	0	0
16) Blytheville.Rice.3000	0	0	0	11550
17) Blytheville.Cotton.4000	0	17500	0	0
18) Blytheville.Cotton.3500	0	0	0	17500
19) Blytheville.Soybean.2000	0	1250	0	0
20) Blytheville.Soybean.1500	0	0	0	1250
21) Newport.Rice. (1000) 3500	0	37800	0	0
22) Newport.Rice.3000	0	0	0	37800
23) Newport.Soybean.2500	0	4700	0	0
24) Newport.Soybean.2000	0	0	0	4700

[1]Optimal acreage represents the total optimal acreage applied with litter given endogenous litter prices. Truck transportation cost at $0.15 and $0.10/ton/mile, 20% increase and 20% decrease in crop base prices at $0.071/lb, $0.606/lb, and $5.858/bu. for rice, cotton and soybean, respectively.

[2]Figures in parenthesis are the optimal rates of litter application to ungraded soils whereas figures outside the parenthesis are the optimal rates of litter application to graded soils.

of marginal product of litter in ungraded soils has gone below the opportunity cost of litter in the local forage production.

Conclusions and Policy Implications

The results suggest that it is economical to transport significant portions of the litter produced from regions with high concentrations of poultry production to areas of major row crop production on graded soils. In fact, in many cases the value of the marginal product of litter as a soil amendment in row crop production exceeds the sum of transportation costs and the value of the marginal product as a fertilizer in local forage production so that the entire available supply could be transported from some source regions. Such a transfer would greatly reduce the threat of non-point source pollution in the regions of high poultry concentration. Of course, the current findings depend on the assumptions such as crop prices at \$0.071/pound of rice, \$0.606/pound of cotton and \$5.858/bu. of soybeans, truck transportation cost at \$0.10/ton/mile and the yield response of crops for litter applications. The optimal rate of litter application for rice is 3500 lbs/A, for cotton 4000 lbs/A and for soybean 2000 lbs/A in the case of graded soils. In the case of ungraded soils, litter application is not recommended for cotton and soybean, whereas, the optimal rate of litter application for rice is 1000 lbs/A. The sensitivity analysis indicates the robustness of the model to changes in crop prices as well as transportation costs.

An industry is currently developing to transport litter for use as a soil amendment in rice production and it has been estimated that 30,000 tons of litter were transported in 1993 (Winrock International). These results suggest that there is tremendous potential for growth in this industry and that as the industry continues to develop even larger quantities of litter can be predicted to be transported. Tharp and Miller indicate that 81% of rice growers plan on using poultry litter in the future. Unfortunately, without government intervention, litter from the region of greatest concentration (Fayetteville) is the least likely to be transported. One of the main reason for such limited transportation of litter is that the cost of transportation from Fayetteville to any destination regions is highest compared to other sources of litter production. In general, the transportation of litter from any source region is limited due reasons such as bulky nature of litter with limited nutrient content, odor problems, storage availability, and absence of an organized market for litter. Possible government interventions include policies such as quantity restriction on litter use in northwest Arkansas, a tax on litter use or land treated with litter in areas of high potential for contamination, and/or a subsidy for transportation. The advantages and disadvantages of the policy options must be carefully analyzed before implementation.

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