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How Far Can Poultry Litter Go? A New Technology for Litter Transport

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Exporting northwest Arkansas excess turkey and broiler litter to partially fertilize nutrient-deficient cropland in eastern Arkansas can be more cost effective than to supply all crop nutrients with chemical fertilizer only, given current high fertilizer prices. Cost savings are greater if litter is baled in ultraviolet resistant plastic and transported via truck, since backhaul opportunities reduce truck rates, or alternatively, if raw litter is shipped via a truck-barge combination. Rice is the crop that allows for greater savings according to a mathematical programming model implemented in General Algebraic Modeling System (GAMS).

Key Words: baling poultry litter, barge transportation, cost minimization, manure management, mathematical programming, nutrient surplus, poultry litter, truck transportation

JEL Classifications: C61, C65, Q12, Q30, Q53

Although people have relied on animal manures to maintain the fertility of agricultural soils for over three millennia, scientific and technological improvements over the last two centuries increased the popularity of commercial fertilizers to the detriment of animal manures and other biomaterials (Beaton). Manure use also declined because its application is more time consuming, may create odor problems, and is not as widely available as commercial fertilizer (Govindasamy and Cochran), or, at least, it has had limited marketability because its transportation cost increases the farther it is shipped. Certain regions face nutrient excess problems (Kellogg et al.) likely due to the dramatic change over the past two decades in the structure of the animal industry in the United States, which has become highly vertically integrated (Vukina and Foster). Farmers' perception of manure management has evolved from crop fertilization to waste disposal (Parker). While inappropriate manure application rates can create environmental stress (Sharpley et al.), properly used poultry manure enhances soil qualities by supplying organic matter, nutrients, enzymes, and bacteria and helping maintain soil pH at desirable acidic levels (Zhang and Hamilton).

The two key poultry counties in Arkansas, Benton and Washington, are located in the northwest part of the state and produce over 237 million broilers per year (USDA-NASS), corresponding to 20% of the state's total broiler production; the production of turkeys and layers is also important to the region. Over the last 20 years, the availability of

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poultry manure was considered a major benefit to poultry growers who relied on this resource to improve pasture yield for cattle production. Because the application rates were nitrogen (N)-based and removal of other nutrients was limited, soil phosphorus (P) levels increased over time. A best management practice (BMP) application rate for pasture land between 9.1 and 11.4 metric tons/hectare (4 and 5 tons/acre) as suggested by Govindasamy and Cochran in 1995 is unsustainable today in Northwest Arkansas. If a P-based application rate were implemented, over 272,000 metric tons (300,000 tons) of surplus poultry litter from these two counties could be available for export annually (Goodwin). Because the populations of Benton and Washington counties have increased more than 74% since the 1990 U.S. Census (the current population surpasses 367,000), additional P problems are caused by municipal and industrial sewage treatment plants, septic tanks, and storm water runoff from lawns, construction sites, and recreational facilities. The survival of the poultry industry in northwest Arkansas requires addressing the excess nutrient problem (the current situation has originated some lawsuits already, e.g., *City of Tulsa v. Tyson Foods, Inc.*).

In an effort to reduce potential P runoff from agriculture in sensitive watersheds, the 2003 Arkansas General Assembly enacted three laws effective in defined sensitive watersheds: (1) Arkansas Soil Nutrient Management Planner and Certification Act, (2) An Act to Register Poultry Feeding Operations, and (3) An Act to Require Proper Application of Nutrients and Utilization of Poultry Litter in Nutrient Surplus Areas (Goodwin et al.). Nutrient management plans are currently being developed for poultry litter that will estimate the excess quantity available for export. The Arkansas Soil and Water Conservation Commission and poultry integrators in northwest Arkansas have offered to help subsidize the transport of excess poultry litter to eastern Arkansas, which is a nutrient-deficient crop area that relies on chemical fertilizers for its nutrient supply. Recent increases in the price of natural gas, a key input in the production of nitrogenous fertilizers, have pushed commercial fertilizer costs upward and revived the interest in manure, particularly poultry litter, as a crop nutrient source.

The purpose of this paper is to evaluate the cost efficiency of alternative transport and handling options for marketing excess poultry litter from northwest Arkansas to crop farmers in eastern Arkansas. We consider poultry litter available from three town sources in Benton and Washington counties. Farm markets for litter are evaluated at county seats in Lonoke, Arkansas, Monroe, Poinsett, Jackson, and Mississippi counties in eastern Arkansas. These counties were earlier identified as potential markets for litter through focus group meetings. Innovations in the present study include a comparison of marketing loose raw litter and plastic-wrapped baled litter, and a comparison of the transport and handling costs between truck and a combination of truck and barge. The transport of litter using barges relies on the Arkansas and Mississippi River systems.

Background and Previous Studies

Willett el al. undertake the issue of reducing soil P levels in the Illinois River Basin (Oklahoma and Arkansas) by limiting local poultry production; the study assumes that off-site litter removal is not an option and litter must be locally land applied. Their results indicate that depending on the target reduction rate, the opportunity cost could range between \$57 and \$71 per metric ton (\$52 and \$65 per ton) of litter reduced. At the basin level, such an approach could cost between \$1.5 million and \$7.7 million. The opportunity costs measure foregone returns from not using poultry litter as a soil amendment and foregone returns from decreased broiler production. They do not take into account other effects, such as changes in the region's consumption, employment, etc., which could increase the opportunity cost.

Another possible solution is to transport the surplus litter to nutrient-deficient regions (Gollehon et al.; Govindasamy and Cochran).

Currently there is no well-established and/or organized marketing structure supporting the long-distance distribution of poultry litter, unlike what exists for commercial fertilizer. Thus, information regarding transport costs and storage is usually inconsistent and many times unavailable, which hinders the development of a poultry litter marketing system. The absence of a market for poultry litter could indicate that nobody has the opportunity of bettering themselves in such a market. But given the undesirable accumulation of nutrients in regions that cannot efficiently use them, the absence of a poultry litter market also indicates a market failure that could warrant public intervention (Gollehon et al.). Parker posits that the absence of a market may be due to high transaction costs on the part of sellers and buyers.

With methods similar to those employed in this paper, Parker defines the value of litter as the cost savings that can be obtained by using litter instead of chemical fertilizer. Despite these savings, a solution at the individual level may not be feasible and a manure brokerage system, with or without the intervention of poultry integrators, may need to be implemented to ensure the success of a manure market in the United States (ibid.). Although traditionally land application of raw litter has been the most common practice, several manure use alternatives that help prevent pollution from excess animal manure application have been evaluated in previous studies, including processing raw litter into a more easily handled form, such as poultry litter pellets, and other new uses such as composting, energy production, and forest fertilization (Lichtenberg, Parker, and Lynch).

Raw litter transport (that is, unprocessed litter) requires attention with respect to sanitary conditions and the use of specialized walking floor or end dump trailers; hence backhaul opportunities, which can reduce transportation costs, although available, are difficult to implement. U.S. Department of Transportation regulations (USDOT-FMCSA), among other things, limit daily working hours for truck drivers to 11 hours following a 10-hour off-duty period, a maximum of 14 hours following a 10-day off-duty period, and require a driver to sleep a minimum of eight consecutive hours each night and spend two additional "consecutive hours either in the sleeper berth, off duty, or any combination of the two." These requirements, while safeguarding drivers, discourage truckers from stopping and cleaning the litter trailers in transit since truckers are paid by distance traveled and cleaning stops limit travel time.

Transport and handling costs for processed forms of litter such as granules or pellets are more economical than raw litter, but the extra processing cost is expensive for agricultural markets, in the range of \$44 to \$55 per metric ton (\$40 to \$50 per ton), and most likely require a subsidy, as is done in the Delmarva Peninsula to export excess poultry litter. Part of these subsidized litter pellets are currently exported as far as eastern Arkansas and are priced above \$110 per metric ton (\$100 per ton) by some local fertilizer dealers, who have indicated that the agricultural market is very limited at this price.[1] The use of subsidies has been addressed in the literature. For the case of Virginia, Pelletier, Pease, and Kenyon examined the impact of a subsidy of no more than \$12/metric ton (\$11/ton) on the litter adoption rate and concluded that 339,300 metric tons (374,000 tons) could be transported annually a distance of 274 km (170 miles) with an average subsidy rate of \$8.70/metric ton (\$7.90/ton). If the litter were to be transported only 161 km (100 miles), then 122,500 metric tons (135,000 tons) could be transported at an annual subsidy cost of \$559,000. Govindasamy and Cochran's study of the feasibility of transporting poultry litter from northwest Arkansas to the Delta concluded that under certain conditions, such long-distance transport is favorable via truck but not rail. The results were sensitive to the litter supply prices considered and to the crop

[1] To elicit current information on litter market practices use, we contacted three dealers that market litter pellets and another dealer that handles sewage sludge granules; we also spoke to five farmers that have used litter pellets.

price. However, the study did not compare the effect of fertilizer costs on the net revenue of litter use. Gollehon et al. also concluded that transportation costs largely determine the economic feasibility of off-farm transport. A welfare analysis of manure use and nutrient standards in Virginia (Feinerman, Bosch, and Pease) concluded that a P nutrient standard would reduce welfare more than a N standard, since the former would require higher transportation costs for litter since litter would have to be shipped to farther locations.

Some of the disadvantages of using raw litter could be offset if the litter could be shipped prepackaged. A possibility is to compress and wrap litter in ultraviolet-resistant plastic bales. This is a new technology that is under development with an expected processing cost of less than $8.80/metric ton ($8 per ton) (Schlotthauer and Goodwin). Bales could offer some special advantages over loose raw litter for handling and transporting including the use of open field storage after farm delivery, better opportunities for truck backhauls to reduce transport cost, preservation of N, and reduced odor problems. However, cutting the plastic and opening the bales at the application site does require a special tractor attachment. Initial field experiments with 40% moisture content baled litter indicated that after the litter had been stored in the bales up to 3 months, the N content was in organic form, pathogen presence was eliminated, odor was reduced to a negligible level, and the consistency of litter had improved making it easier to spread (Schlotthauer and Goodwin). Current work is being done to expand the potential litter baling.

Another issue that affects the cost of moving litter is the method of transportation. Truck and/or rail have been the focus of previous studies (for example see Govindasamy and Cochran; Jones and D'Souza) but barge transportation in this context has not been investigated. Given the existence of good fluvial waterways in Arkansas, a combination of truck and barge to transport poultry litter across the state is a real possibility. Barge rates along the Arkansas and Mississippi rivers also are very competitive for long-distance transport compared with truck rates. In Jones and D'Souza's study a goal-focused model was used to determine optimal litter shipments among watersheds in the eastern panhandle of West Virginia; they assumed unprocessed litter was transported by truck. Rail transportation, which was considered in Govindasamy and Cochran's study, was initially contemplated for this study but we were unable to obtain the necessary details from the railroad company on appropriate routing and cost information.[2]

Method of Analysis

This analysis uses a linear programming model executed with the MINOS algorithm available in GAMS. The objective of the model is to minimize the cost of supplying nutrients to crops in eastern Arkansas. The nutrient cost function accounts for chemical fertilizer costs and poultry litter costs assuming litter is exported from northwest Arkansas to eastern Arkansas. In the optimization we evaluate loose raw litter and litter that has been compressed and plastic-wrapped into bales; we analyze transportation using truck-only vs. a truck-barge combination.

We also take into account the cost of short-distance truck transport needed to move litter off the farm and to and from barge ports. In the case of raw litter we considered the transportation costs from storage buildings in eastern Arkansas to farm fields when farmers want to spread the raw litter. Baled litter is assumed to be delivered and stored outside in farm fields in eastern Arkansas prior to spreading, since the bales take little space and do not need to be covered, as supported by field tests. The cost of using litter includes transporting, storing, handling, processing (in the case of baled litter), spreading, and incorporation costs and is compared with the cost of using commercial fertilizer. The objective function of the mathematical programming model is defined as

[2] Union Pacific had considered the project infeasible at the time of research but has since contacted the authors with potential renewed interest.

Table 1. Definition of Symbols Used in Mathematical Programming Model

Symbol	Definition
Z	Total dollar cost of supplying nutrients to county markets in the form of poultry litter or chemical fertilizer
LT_{smrj}	Acres of land in market m cultivated with crop r and fertilized with type j litter shipped by truck from source s
LB_{sunmrj}	Acres of land in market m cultivated with crop r and fertilized with type j litter shipped by truck and barge from source s and going through ports u and n
FA_{mr}	Acres of land in market m cultivated with crop r and fertilized with chemical fertilizer only
α_r	Tons per acre of litter applied to crop r to meet phosphorus requirements
θ_{rf}	Tons per acre of chemical fertilizer of nutrient f applied to crop r when enough litter is applied to meet the phosphorus requirements of the crop
ϕ_{rf}	Tons per acre of chemical fertilizer of nutrient f applied to crop r when no litter is applied
β_{smj}	Cost per ton of using litter of type j transported from town source s to county market m by truck only
δ_{sunmj}	Cost per ton of using litter of type j transported from town source s to county market m by truck and barge going through ports u and n
γ_r	Application cost per acre of chemical fertilizer in land also receiving poultry litter
η_r	Application cost per acre of chemical fertilizer in land receiving no poultry litter
ρ_f	Price per ton of commercial fertilizer for nutrient f
κ_f	Content of chemical fertilizer in pounds of nutrient f
ξ_f	Content of poultry litter in pounds of nutrient f
λ_{rf}	Requirements of crop r in terms of nutrient f
$\overline{L_w}$	Tons of poultry litter produced in watershed w
$\overline{A_{mr}}$	Acreage cultivated with crop r in market m

$$
\begin{aligned}
(1)\quad & \min_{LT_{smrj},\, LB_{sunmrj}} Z \\
&= \sum_s \sum_m \sum_r \sum_j \left[\left(\alpha_r \beta_{smj} + \gamma_r + \sum_f (\theta_{rf}\rho_f)\right) LT_{smrj}\right] \\
&+ \sum_s \sum_u \sum_n \sum_m \sum_r \sum_j \left[\left(\alpha_r \delta_{sunmrj} + \gamma_r + \sum_f (\theta_{rf}\rho_f)\right) LB_{sunmrj}\right] \\
&+ \sum_m \sum_r \left[\left(\eta_r + \sum_f (\phi_{rf}\rho_f)\right) FA_{mr}\right].
\end{aligned}
$$

Refer to Table 1 for an easy reference to the symbols used in the model. The variable Z in the objective function represents the total dollar cost of supplying nutrients to county markets in the form of poultry litter or chemical fertilizer; LT_{smrj} represents acres of land in market m cultivated with crop r and being fertilized with poultry litter of type j (baled or loose) transported by truck from source s and also with chemical fertilizer; LB_{sunmrj} similarly represents acres of land in market m cultivated with crop r and being fertilized with chemical fertilizer and with poultry litter of type j transported by truck and barge going through ports u and n; and FA_{mr} represents acres of land in market m cultivated with crop r and fertilized with chemical fertilizer only. LT_{smrj} and LB_{sunmrj} are the choice variables of the optimization model.

In the above equation, α_r is defined as the application rate (tons/acre) of litter applied to crop r. We assume that in the land receiving poultry litter and chemical fertilizer, litter is applied first in such a way as to meet the P nutrient requirements of the crop, which we denote as $\lambda_{r\text{"P"}}$ (we denote the nutrient requirements of crop r in terms of nutrient f as λ_{rf}). Given the P content of litter, denoted as $\xi_{\text{"P"}}$, then $\alpha_r = \xi_{\text{"P"}}/\lambda_{r\text{"P"}}$. The remaining crop nutrients required are supplied with chemical fertilizer. Define κ_f as the chemical fertilizer nutrient content (lbs./ton), then θ_{rf}, the application rate (tons/acre) of chemical fertilizer of type f needed to provide the remaining nutrients to crop r, is defined as θ_{rf}. For the land where only chemical fertilizer is applied, the application rate of chemical fertilizer is $\phi_{rf} = \lambda_{rf}/\kappa_f$. The cost parameters in the objective function are β_{smj} defined as the cost per ton of using litter of type j transported by truck from source s to market m; δ_{sunmj} defined as the cost per ton of using litter of type j transported by truck and barge from source s to market m going through ports u and n; γ_r is the application cost per acre of chemical fertilizer when the crop is also fertilized with poultry litter; η_r is the application cost per acre of chemical fertilizer when the crop is not fertilized with litter (thus, $\eta_r \geq \gamma_r$, as, when fertilized chemically, most crops receive multiple fertilizer applications in one growing season); and ρ_f is the price of chemical fertilizer for nutrient f.

The first constraint, Equation (2), in the problem limits the availability of poultry litter shipped from the town sources s (being that each town source is associated with a watershed, say w) to the maximum amount of litter produced in that watershed, $\overline{L_w}$. The constraint is defined as

$$(2)\quad \sum_s \sum_m \sum_r \sum_j \left[\alpha_r \left(LT_{smrj} + \sum_{un} LB_{sunmrj}\right) I(s \in w)\right] \leq \overline{L_w}, \quad \forall w.$$

The second constraint, Equation (3), states that the land being considered must be fertilized either with chemical fertilizer or with a combination of chemical fertilizer and poultry litter such that the acreage being fertilized must be exactly equal to the available acreage in each market cultivated with crop r, $\overline{A_{mr}}$. Mathematically, we state this as

$$(3)\quad \sum_s \sum_j \left[LT_{smrj} + \sum_u \sum_n LB_{sunmrj}\right] + FA_{mr} = \overline{A_{mr}}, \quad \forall m, r.$$

Finally, the nonnegativity constraints are defined as

$$(4)\quad LT_{smrj}, LB_{sunmrj}, FA_{mr} \geq 0, \forall s, u, n, m, r, f, j.$$

The objective function of the GAMS model, Equation (1), includes all costs pertaining to supplying crops (corn, soybeans, rice, wheat, cotton, and grain sorghum) at each market (Lonoke, Arkansas, Monroe, Jackson, Poinsett, and Mississippi counties in Arkansas) with N, P_2O_5, and K_2O by applying poultry litter or chemical fertilizer (urea, super phosphate, or potash fertilizer). Poultry litter is transported out of the Eucha-Spavinaw Watershed (ESW) from Decatur in Benton County and out of the Illinois River Watershed (IRW) from Siloam Springs and/or Prairie Grove in Washington County. The nutrient supply costs in the model refer to the costs incurred for litter transportation, loading and unloading, raw litter storage and handling, processing costs for baled litter, application and incorporation costs of litter, and costs of chemical fertilizers and respective application. When shipping by barge, the choices of outgoing ports on the Arkansas River for litter from northwest Arkansas are Catoosa (Oklahoma) or Fort Smith (Arkansas). The incoming ports evaluated for receiving litter in eastern Arkansas are Pendleton, Pine Bluff, and Little Rock on the Arkansas River and Hickman on the Mississippi River in Mississippi County.

Data Inputs

In 2004 it was estimated that about 97,430 metric tons (107,400 tons) of broiler and turkey litter are produced in the ESW annually and 185,524 metric tons (204,506 tons) in the IRW (Goodwin). These production levels are set as the upper bound on the litter supply constraint (Equation 2). We assume the concentration of N, P_2O_5, and K_2O in northwest Arkansas poultry litter is on average 30, 28, 26 kg/metric ton (60, 57, 52 lbs/ton) (James). Our model assumes that only 70% of N in litter is available to meet the crops' nutrient requirements (Moore). Because one of the most common critiques of poultry litter use is the possibility of N volatilization to the atmosphere as ammonia—litter management practices are a key issue in this respect—in one of the sensitivity analysis

Table 2. Summary of Cost Data Parameters of Using Poultry Litter in Bales and Unbaled

Item	Unit	Value	Item	Unit	Value
Baled Litter			Unbaled (Raw) Litter		
Capital Costs			*Capital Costs*		
Litter baler	$/ton	1.33	Conveyor	$/ton	0.09
Conveyor	$/ton	0.09	Bobcat	$/ton	0.13
Bobcat	$/ton	0.13	Trailer	$/ton	0.03
Trailer	$/ton	0.03	Truck for trailer	$/ton	0.08
Truck for trailer	$/ton	0.08	*Site costs*		
Front loader	$/ton	0.06	Office	$/ton	0.02
Generator	$/ton	0.11	Scales	$/ton	0.04
Fork lift	$/ton	0.05	Land	$/ton	0.18
Site Costs if Developed			Infrastructure	$/ton	0.12
Baler building	$/ton	0.28	*Operating Costs*		
Office	$/ton	0.02	Record keeping	$/ton	0.20
Scales	$/ton	0.04	Supervision	$/ton	0.50
Land	$/ton	0.18	Field foreman	$/ton	0.24
Infrastructure	$/ton	0.12	*Other Costs*		
Operating Costs			Obtaining litter from farm	$/ton	7.00
Hauling litter to baler site	$/ton	9.00	Load litter in truck	$/ton	2.00
Loading litter to baler	$/ton	2.00	Unload litter from truck	$/ton	2.00
Utility costs	$/ton	0.15	Cleaning fee for trucks	$/ton	2.00
Baling labor	$/ton	0.40	Storage in hoop building	$/ton	3.00
Plastic cost	$/ton	2.81	Unload litter to spreader	$/ton	2.00
Equipment maintenance	$/ton	0.15	Application	$/ton	7.00
Equipment operation	$/ton	0.45	Disking	$/ton	6.00
Record keeping	$/ton	0.20			
Supervision	$/ton	0.50			
Field foreman	$/ton	0.24			
Other Costs					
Obtaining litter from farm	$/ton	7.00			
Load bales	$/ton	2.00			
Unload bales from truck	$/ton	2.00			
Unload baled litter to spreader	$/ton	3.00			
Land apply litter	$/ton	7.00			

Sources: Litter baling costs obtained from Mammoth, Inc. Equipment costs obtained from University of Arkansas Extension budgets and from local dealers: Eagle Body, Inc. (Springdale, AR); Williams Tractor, Inc. (Fayetteville, AR), and Landers Toyota North (Fayetteville, AR). Land costs obtained from NWARMLS Board of Realtors® Broker Reciprocity Real Estate Search engine (http://www.qtimls.com/nwarmls/) and from Tom Skipper, a local real estate agent (http://www.tomskipper.com).

scenarios, we assumed that N availability in litter was reduced from 70% to 50% in the first year. For chemical fertilizer, we assumed 100% N availability. Although Feinerman, Bosch, and Pease assume that litter leaves the grower farm free on board, we assume that litter to be used in raw or baled form could be obtained from the farm for $7.70/metric ton ($7/ton). This amount covers any trucking expenses to the town source as well as a small monetary fee for the poultry grower, who would also get the poultry houses cleaned at no cost. We consulted the Arkansas extension budgets to obtain costs and rates for chemical fertilizer application (UA-CES). Refer to Table 2 for a list of the parameters used in the model.

Our contacts with truckers (Traylor; Mitchell) indicate that long-distance bale transport by truck with a 21.3-metric ton (23.5-ton) trailer could be priced at the backhaul rate of $1.00 per

Table 3. Transport Parameters for Barge and Trucks

Transport	Unit	Value
Barge transport costs		
Barge capacity	ton	1,500
From Catoosa to Little Rock	$/ton	8.07
From Catoosa to Pine Bluff	$/ton	9.04
From Catoosa to Pendleton	$/ton	9.44
From Catoosa to Hickman	$/ton	16.37
From Fort Smith to Little Rock	$/ton	8.50
From Fort Smith to Pine Bluff	$/ton	9.34
From Fort Smith to Pendleton	$/ton	9.74
From Fort Smith to Hickman	$/ton	16.97
Truck transport costs		
Large truck capacity	ton	23.50
Short-distance truck capacity	ton	8.00
Average distance to farm	miles	10.00
Baled litter with backhaul	$/loaded mile	1.60
Raw litter (up to 100 miles)	$/loaded mile	3.35
Raw litter	$/loaded mile	2.70
Small truck	$/loaded mile	3.00

Sources: Barge rates are averages of quotes provided by D. Choate, W. Schmidt, and J. Weber. Trucking costs are averages of quotes provided by M. Traylor and L. Mitchell.
Notes: Barge rates already include a $500 allowance for cleanup costs.

loaded kilometer ($1.60 per loaded mile) with bales delivered directly to farmers for outside storage at the application field. Thus, in the baseline model, truck transportation of baled litter has a lower cost of $1.00 versus $1.68 per loaded kilometer ($1.60 versus $2.70 per loaded mile) due to the better availability of truck backhaul opportunities compared with transporting loose raw litter (see Table 3). In one of the sensitivity analysis scenarios we relaxed the assumption of backhaul availability. Backhauls are much more difficult in loose raw litter transport because the trailers must be cleaned before transporting other materials; however, sometimes opportunities are available to backhaul bedding materials to the farm where the litter originated.

Short-distance truck transport of less than 160 kilometers (100 miles) with a 21.3-metric ton (23.5-ton) load with either bales or raw litter is priced at $2.08 per loaded kilometer ($3.35 per loaded mile). We assume a $100 minimum charge per truckload for use of large trucks, regardless of distance. These short-haul trucking rates for baled and loose raw litter are applied to all trips to and from the barge ports. Barge rates were quoted by David Choate and already include a $500 flat fee allowance for cleaning. No extra in-transit costs are assumed for long-distance trucking.

Baled litter is assumed to be delivered directly to farm fields in eastern Arkansas for outside storage prior to spreading. No storage costs for baled litter are included since the bales are fully plastic wrapped to preserve nutrients, provide an odor barrier, and protect against the weather. Loose raw litter is assumed to be delivered to an inside storage building in eastern Arkansas with a storage cost of $3.30 per metric ton ($3 per ton) plus additional transport and handling costs from the storage building to the farm field of $7.70 per metric ton ($7 per ton), including storage cleanout and unloading costs (Table 2). Field spreading costs per metric ton are $7.70 for raw litter and baled litter ($7 per ton). A special front end loader attachment is needed to open the bales; thus unloading baled litter to the spreader is $1 more expensive than the $2 assumed to load loose raw litter to the spreader. Litter incorporation with a disk plow in the field to prevent ammonia N losses after spreading is $6.60 per metric ton ($6/ton) for loose raw litter; we assume that baled litter does not need to be disked in the soil because according to field trials most of the N content is in organic form (Schlotthauer and Goodwin).

Chemical fertilizer prices as indicated in the 2006 extension budgets were $387.32 per metric ton of urea ($352.46 per ton), $310 per metric ton of super phosphate ($282 per ton), and $275 per metric ton of potash fertilizer ($250 per ton). Spreading costs for chemical fertilizer depend on which crop fertilizer is to be applied and were obtained from extension budgets (UA-CES). Recommended N-P_2O_5-K_2O nutrient requirements for corn, soybean, rice, wheat, cotton, and grain sorghum crops are supplied with chemical fertilizer and/or poultry litter. The crop nutrient requirements are based on application rates recommended by extension publications of the University of Arkansas (ibid.). We must note that according to the crop budgets, fertilizer application does not occur all at once. Each crop has a different schedule for fertilizer application. For example, for rice it is advised that the soil be fertilized four times: a preplant application and three other applications after planting. This fact was incorporated in our analysis by reducing the application cost of fertilizer when poultry litter is also used. Crop acreage at each county market was obtained from the 2002 Census of Agriculture. Total crop acreage in the six eastern Arkansas counties evaluated in this study is 850,000 hectares (2.1 million acres).

Four alternative scenarios are considered in the sensitivity analysis of the model: (1) exclusion of litter baling as an option, (2) unavailability of backhauls for trucking baled litter, which increases trucking rates for bales from \$1.00 to \$1.68 per loaded kilometer (\$1.60 to \$2.70 per loaded mile), (3) a 50% reduction in the prices of chemical fertilizer, and (4) reduction in N availability in litter from 70% to 50%.

Results and Sensitivity Analysis

All the crop nutrient needs could be met by chemical fertilizer at a total cost of \$139,790,720 under the above described assumptions. The solution to our baseline model indicates that some cost savings could be obtained by substituting poultry litter for chemical fertilizer; accordingly, the optimal value of the objective function would be \$137,173,158, which corresponds to the minimum cost of supplying nutrients to the crops considered in the study area. The least cost solution would be to transport baled litter by truck from Prairie Grove in the IRW to use in the production of rice in Lonoke (28,608 hectares [70,693 acres]), Arkansas (6,646 hectares [16,422 acres]), Monroe (23,280 hectares [57,527 acres]), and Poinsett (20,088 hectares [49,639 acres]); the litter from the ESW would be transported from Decatur to Arkansas County (41,290 hectares [102,030 acres]) and applied to rice as well. Note that current field research (Slaton et al.) does indicate that poultry litter is an adequate alternative to chemical fertilizer with respect to P and K in the production of rice; with respect to N, poultry litter can serve as starter fertilizer while the N in litter mineralizes during the growing season.

The same field research (ibid.) also suggests that the rate of mineralization of litter N can be manipulated by selecting when to flood the rice after litter has been applied. According to our results, all the rice acreage in Lonoke and Monroe counties would receive poultry litter. All the litter produced in the ESW would be moved to Arkansas County and the remaining rice acreage in this county would receive litter produced within the IRW. The difference between the nutrient needs and the nutrients provided by the litter would be met through the application of chemical fertilizer.

Under the baseline scenario, it would be optimal to export all the litter produced in both watersheds (Table 4). The cost of using the litter (including shipping, processing, etc.) would be \$16.2 million, which would yield an average price per ton of litter in the neighborhood of \$51.87 (this is not a uniform cost because the transportation component of the cost of using litter varies by location). According to the most recent extension budgets, during a growing season, it costs as much as \$243.30/hectare (\$97.33/acre) to fertilize rice with chemical fertilizer plus an additional \$53.50/hectare (\$21.40/acre) for spreading fees, adding up to a total cost of \$297/hectare (\$119/acre). The results from our model indicate that rice could be fertilized with a combination of chemical fertilizer and litter at an average cost of \$267/hectare (\$107/acre), resulting in average savings of at least \$30/hectare (\$12/acre). The marginal cost associated with the poultry litter supply constraint (Equation 2) indicates that an additional 0.91 metric tons (1 ton) of poultry litter produced in the ESW could decrease the objective function cost by \$4.71; if an additional 0.91 metric tons (1 ton) of litter were produced in the IRW, the value of the

Table 4. Summary of GAMS Optimization Model Solutions of Using Northwest Arkansas Poultry Litter and Chemical Fertilizer to Supply Nutrients to Eastern Arkansas Crops

Component/Scenario	Baseline	No Baling	No Backhauls	Cheap Fertilizer[a]	Less Litter N[b]
Litter use (tons)	311,906	74,413	119,100	0	311,906
Litter form (raw/bales)	Bales	Raw	Bales	—	Bales
Transport method	Truck	Truck	Truck and barge	—	Truck
Litter supply cost ($/ton)	51.87	58.50	58.67	0.00	51.87
Total litter cost ($ m)	16.179	4.353	11.681	0.000	16.179
Total litter and fertilizer cost ($ m)[c]	137.173	139.660	139.473	80.878	138.607
Area receiving litter (acres)	296,311	70,693	189,145	0	204,483
Crops fertilized	Rice	Rice	Rice	—	Rice

[a] Chemical fertilizer prices per ton reduced from $352.46 to $179.23 for urea, $282 to $141.40 for phosphate, and $250 to $125 for potash.

[b] N availability from poultry litter reduced from 70% to 50%.

[c] Estimated total chemical fertilizer cost to meet crop nutrient requirements on 2.1 million crop acres in Lonoke, Arkansas, Monroe, Jackson, Poinsett and Mississippi counties in combination with use of poultry litter.

objective function could be reduced by $7.23 (Table 5).

The first scenario in our sensitivity analysis is meant to determine the effect in terms of litter use, cost, and crop and market allocation of not being able to process the litter into plastic-wrapped bales. If baling is not an option, the truck transportation rate would be higher because there would be no back-hauls and we would only consider those costs associated with using loose raw litter. Our results indicate that a portion of poultry litter use would still be cost efficient. Although it would not be optimal to remove any litter from the ESW, the optimal solution indicates that 67,506 metric tons (74,413 tons) would be removed from the IRW via truck and applied to 28,608 hectares (70,693 acres) of rice in Lonoke County (Table 4). Hence the marginal costs associated with the supply constraint are both zero (Table 5). The optimal value of the objective function would be $139,659,820, of which $4,353,470 would correspond to the cost of using poultry litter. The average cost of using poultry litter would be $64.29/metric ton ($58.50/ton).

For the second scenario we assumed that poultry litter could be baled but that there were no backhaul opportunities; thus in this instance the only real change would be the truck transportation rate. Under this option, the optimal solution would be to transport 180,620 metric tons (199,100 tons) of baled litter from the IRW via truck and barge to be applied to rice in Lonoke and Arkansas counties. The optimal routes and acreage covered would be Prairie Grove/Fort Smith/Little Rock/Lonoke (28,608 hectares [70,693 acres]) and Prairie Grove/Fort Smith/Pine Bluff/Arkansas (47936 hectares [118,452 acres]). Because it would not be optimal to remove all litter from any of the two watersheds, the marginal cost associated with the supply constraint would be zero (Table 5).

Table 5. Sensitivity Analysis of Marginal Costs Associated with Litter Supply Constraint

Scenario	Supply Constraint Binding?	Eucha-Spavinaw Watershed	Illinois River Watershed
Baseline model	Yes	($4.709)	($7.257)
Cheap fertilizer	No	—	—
Less litter N	Yes	($0.112)	($2.660)
No baling	No	—	—
No backhauls	No	—	—

The value of the optimal solution would be \$139,473,234 and the cost of using litter would be \$11,680,819 (Table 4).

In the third sensitivity analysis scenario, we halved the price of chemical fertilizer. The optimal strategy for this scenario would be to not use litter and simply supply the nutrients to the crops using chemical fertilizer. The value of the objective function would be \$80,878,246.

Scenario four assumed that the amount of N in litter available to crops would be 50% instead of the original 70%. The optimal solution would be to use all the litter produced in ESW and IRW by transporting it in bales via trucks. The actual litter allocation between source towns and county markets is exactly the same as in the baseline scenario, and rice is the optimal crop on which to apply litter, but the costs of supplying the nutrients would change. The value of the objective function would increase to \$138,607,085 because more commercial fertilizer would need to be supplied to meet the crop requirements. The marginal cost associated with the supply constraint indicates that the value of the objective function would be reduced by \$0.11 if an additional 0.91 metric tons (1 ton) of litter became available from ESW and by \$2.66 for litter from IRW.

Summary and Conclusions

The objective of this study was to evaluate the cost efficiency of supplying nutrients to crops in eastern Arkansas by using a mix of poultry litter and chemical fertilizer. This would allow exporting excess poultry litter from northwest Arkansas to eastern Arkansas farm counties that are nutrient deficient. We assessed innovative transport and handling options: baling the litter before long-distance transport and using a combination of truck and barge transport methods. Litter is valued in terms of how much it would cost to use it to supply nutrients to crops as an alternative to regular chemical fertilizer. Litter supply costs considered include all transport, special handling and storage, field spreading, and field incorporation costs. A payment of about \$2.20/metric ton (\$2/ton) is included to purchase the litter in northwest Arkansas, since land application of litter has come under increased scrutiny because of water quality issues; we also assume that the poultry producer benefits from having the poultry house cleaned. Expected processing costs for baling litter are included.

Results indicate that poultry litter export is cost efficient under all scenarios with the exception of really low chemical fertilizer prices. If litter users were willing to pay for poultry litter nutrients at the same level as chemical fertilizer prices, litter exports would not require a subsidy given current chemical fertilizer prices; this result would not hold if chemical fertilizer costs were halved. The baling option with backhaul trucking rates would be the least cost litter supply scenario. Without baling or backhaul trucking rates, it would still be cost efficient to transport part of the litter and use it instead of chemical fertilizer.

Based on our results, there is a potential market for poultry litter in Eastern Arkansas without the need for public subsidies. The fact that this market has not fully developed indicates that there are asymmetric information problems that warrant public intervention in the form of an education campaign of stakeholders. If a market for poultry litter is fully developed, several benefits will be attained including reduced environmental stress in areas of excess nutrients, lower production costs for crop producers, and less demand for chemical fertilizer, which reduces demand for fossil fuels. However, long-distance transportation of poultry litter will increase demand for fuel. An analysis of these benefits and costs is beyond the scope of this paper but should be pursued in further research.

Some caveats in this research are that the litter baler is still under development and the costs and performance still have not been tested under actual production conditions. Crop growers may not be willing to pay the full nutrient value of litter because of other considerations such as the volatility of both the N content in litter and the N availability to crops (which is very sensitive to management issues of raw litter but is not considered a problem when using baled litter), the lack of litter spreading equipment in eastern Arkansas, the general lack of market services to supply litter compared with chemical fertilizers, and the relative short window of application for most crops due to uncertainties in soil moisture conditions and labor shortages. Crop farmers may be willing to pay more for litter bales than loose raw litter because of better nutrient preservation and improved storage and handling properties; transporting/using baled litter could be more cost efficient than loose/raw litter because of lower trucking rates and savings from not having to incorporate the litter.

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