LEAST COST SOLUTIONS FOR REMOVING POULTRY LITTER FROM THE EUCHA-SPAVINAW WATERSHED UNDER PHOSPHOROUS RESTRICTIONS

By

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CHAPTER 1

INTRODUCTION

Background

Americans have substantially increased their consumption of red meat, poultry, and fish over the last 50 years. According to the USDA Agriculture Fact Book 2000, in 1999 each American consumed an average of 12 pounds more red meat, 48 pounds more poultry, and 4 pounds more fish & shellfish than in the 1950s. The increase in poultry consumption is especially pronounced (Table I.1).

Table I-1. Meat Consumption in the U.S 1950-1999[1]

Annual Average Item	1950-59	1960-69	1970-79	1980-89	1990-99	1998	1999
Pounds per capita, boneless-trimmed weight							
Total meats	133.0	161.8	177.1	182.9	190.7	195.3	197.2
Red meat	102.3	123.4	129.4	121.9	113.3	115.6	113.9
Beef	52.8	69.1	80.9	71.8	63.7	64.9	63.5
Pork	41.0	47.9	45.0	47.7	48.0	49.1	49.1
Veal & lamb	8.5	6.4	3.5	2.4	1.6	1.6	1.3
Poultry	19.8	27.7	35.2	46.8	62.6	65.0	68.4
Chicken	16.2	22.5	28.4	36.9	48.5	50.8	54.4
Turkey	3.5	5.1	6.8	9.9	14.1	14.2	14.1
Fish & shellfish	10.9	10.7	12.5	14.2	14.8	14.8	14.8

[1]Adapted from USDA Agricultural Fact Book, 2000

This large increase in consumption is attributed to rising consumer incomes, particularly an increase in two-income households, as well as decreases in real prices of meat and, especially, poultry. In addition, the meat industry has provided various new product including value added products processed for consumers' convenience, and many new products for food service operators.

Along with the growing demand, poultry industries have largely grown from backyard operations which provided supplemental income for the family to vertically integrated industries. Referring Watt Poultry USA, January 2004, Tyson Foods, Inc. reported that in 2003 U.S. processors slaughtered 165.58 million pounds of chicken, of which Tyson Food Inc. processed 26%, Pilgrims' Pride Corporation processed 16%, Gold Kist Inc. processed 9%, and Perdue Farm processed 7%. The remaining 42% was processed by other small companies.

To satisfy the large scale production and consumption trend of poultry products many grower houses have been established in many parts of the U.S. The 2002 Census of Agriculture data indicated that in 1997, 51,423 farms produced 8.01 billion birds. By 2002, 67,256 farms produced 9.2 billion birds (Table I.2).

Table I-2. U.S. Poultry Production 2002

Item	Farms	Numbers	Dry manure[1] Tons (for 2002)
Layers	18,621	202,947,490	1,420,632.43
Pullets	8,193	174,916,701	472,275.09
Broilers	32,006	8,500,313,357	41,651,535.45
Turkeys	8,436	283,247,649	3,087,399.37
Total	67,256	9,161,425,197	46,631,842

Source: U.S. Census of Agriculture, 2002

[1] Broiler manure based on 4.9 kg dry manure/bird/year, for layer 7kg , for pullets 2.7kg, for turkey 10.9 kg (Sims et al., 1989)

Currently, poultry production in the United States is concentrated in the Southeastern states. Using the 2002 census by state level, the total production in this region for 2002 is 5.89 billion birds, about 64% of production (Table I.3).

Table I-3. Poultry and Dry Manure Production in Southeastern United States in 2002[1]

States	Number					
	Farms	Layers	Pullets	broilers	Turkeys	Total
Arkansas	5,023	9,124,085	14,811,501	1,181,907,700	28,459,783	1,234,303,069
Tons of litter		*63,869*	*39,991*	*5,791,348*	*310,212*	*6,205,419*
Georgia	3,640	15,217,322	13,885,761	1,288,543,081	712	1,317,646,876
Tons of litter		*106,521*	*37,492*	*6,313,861*	*8*	*6,457,882*
Alabama	3,414	7,659,735	10,298,701	1,050,885,771	NA	1,068,844,207
Tons of litter		*53,618*	*27,806*	*5,149,340*		*5,230,765*
Louisiana	886	1,238,308	1,123,656	216,941,912	268	219,304,144
Tons of litter		*8,668*	*3,034*	*1,063,015*	*3*	*1,074,720*
Mississippi	2,539	3,009,286	6,140,062	752,632,925	1,701	761,783,974
Tons of litter		*21,065*	*16,578*	*3,687,901*	*19*	*3,725,563*
N.Carolina	4,442	8,590,685	11,835,396	739,566,977	50,896,556	810,889,614
Tons of litter		*60,135*	*31,956*	*3,623,878*	*554,772*	*4,270,741*
Oklahoma	1,994	3,027,523	3,316,431	231,877,714	933,382	239,155,050
Tons of litter		*21,193*	*8,954*	*1,136,201*	*10,174*	*1,176,522*
S.Carolina	921	4,469,553	7,603,504	181,792,956	18,085,815	211,951,828
Tons of litter		*31,287*	*20,529*	*890,785*	*197,135*	*1,139,737*
Total	22,859	52,671,566	69,180,823	5,670,914,581	99,253,404	5,892,020,374
					Total dry litter	*29,281,349*

[1] Data adapted from 2002 census of agriculture

The Problem

According to Kelleher et al., the three wastes of primary concern in poultry production are bedding litter used for poultry housing, the manure resulting from poultry production and dead birds. This review looks at disposal options for the first two materials. Using the Sims et al. assumptions for dry manure estimation, in the year 2002 about 46.6 million tons of poultry litter is produced in the U.S., with 1.2 million tons (2.5 % of the national poultry waste) of this produced in Oklahoma. Oklahoma and Arkansas together produce 7.38 million tons, or 15.8% of the national poultry waste. Disposing of this litter has become a problem

According to Ancev, the relaxation of laws prohibiting corporate farming, first in Arkansas and then in Oklahoma, has aided further growth of concentrated animal feeding operations. These concentrated animal feeding operations tend to locate in relatively small geographic areas, including eastern Oklahoma and western Arkansas. The Eucha-Spavinaw watershed is predominantly located in Oklahoma's Delaware county and Arkansas' Benton county.

Because land application of raw litter has been the simplest and least cost method of disposal, most of these poultry wastes have been used as a crop fertilizer. Evers noted that over 95% of U.S. poultry litter is applied to agricultural land as fertilizer. The problem with land application is that it has been confined to areas near poultry production. Bosch and Napit observed that poultry are produced in spatially concentrated areas to minimize feed and transportation costs.

Land application of broiler litter in eastern Oklahoma and western Arkansas has become a major pollution concern since the 1980s. In particular, eutrophication of lakes Eucha and Spavinaw has been blamed on high phosphorous (P) loading in the watershed attributed to land application of litter produced by intensive poultry production (Storm et al.). The Oklahoma Water Quality Standard (OWRD, 2004) defines eutrophication as a condition in which a body of water changes from one of low biological productivity and clear water to one of high productivity and water made turbid by accelerated growth of algae. Water from eutrophicated lakes is not suitable for drinking due to bad taste caused by algal blooms. Moreover, the eutrophication reduces the recreation value of these lakes.

There is also concern about the overall ecological impact of phosphorous pollution in the watershed. Efforts by municipal water treatment facilities to achieve good-tasting drinking water are expensive.

In order to mitigate this serious problem some regulatory steps have been taken. The Oklahoma Water Quality Standard (OWRB, 2004) designated the beneficial use of Eucha and Spavinaw lakes as public and private water supply, aquatic community, agricultural irrigation, recreation and aesthetics and sensitive drinking water supply. The report also recommended a 54% and 44.6% reduction in P flowing into Lakes Eucha and Spavinaw, respectively, to achieve the desired tropic state. Estimation by Storm et al showed that the current P loading of Lake Eucha has already reached 47,600 kg per year. Of this, 24% is attributed to point source pollution such as the City of Decatur wastewater treatment plant, and 73% is attributed to land application of litter. The Oklahoma Water Quality Board promulgation set total phosphorus criteria of a maximum of 0.037/mg/L in scenic rivers with full compliance by 2012.

Several practices have been proposed to reduce the amount of P loading. They include applying litter to land that is less susceptible to P runoff and applying alum to either the litter or the land (Ancev). Although these practices are beneficial, they may not be sustainable because the available land is limited, and litter production at current rates may soon exceed the land's saturation point. Also, these practices increase cost of litter management.

Some have proposed transporting the litter out of the region to areas where its value as fertilizer is higher. But due to the low nutrient content of litter and thus the high volume required to be an effective fertilizer, it is not economical to transport the litter long distances for use as a plant nutrient (Poudel and McIntosh; Cochran and Govindasamy). The Oklahoma Legislature enacted the Oklahoma Poultry Waste Act in 2001, which provides tax relief to parties that transport poultry waste from region where it is abundant and creates an environmental problem, such as eastern Oklahoma, to regions where P lacking such as central Oklahoma (Oklahoma Statutes 2002).

Another solution is processing the litter into electricity and saleable fertilizer products. Preliminary results of such research show that this solution will be more economical if the processing plant is large enough to process litter from several poultry farms, because of economies of size.

These alternatives have the potential to reduce P loading. But when they are implemented individually they are economical only for a certain level and capacity of operation. For instance, because of economies of size, processing of litter is likely to be cost-effective in increments of processing capacity of at least 100,000 tons of litter per year (Mapemba). Transporting of litter outside the region may be economically feasible depending on how far the litter must be transported. Bosch and Napit concluded that surplus litter could be shipped economically if the distance transported was 50 miles, with a shipment cost of $18.86/ton or less. Since this alternative is more likely to be economically feasible for small amounts of litter and for nearby areas that are P-deficit, and since a processing plant is more likely to be feasible for large amounts of geographically concentrated litter, a combination of these two alternatives may be better than either one individually. The purpose of this research is to determine if a combination of processing litter within the region and transporting litter outside the region is more economical than either of the two solutions individually.

Objectives

The general objective of this study is to find economically feasible alternatives for reducing phosphorous runoff in Eucha-Spavinaw watershed resulting from poultry litter application. The specific objectives are to determine the economically optimum number, size and location of plants to process litter into salable fertilizer and electricity; and the optimum amount of litter to be transported out of the watershed to phosphorous deficit areas.

Organization of the study

The conceptual framework is presented in Chapter II. Relevant literature is reviewed in Chapter III. Empirical procedures and data sources are presented in Chapter IV. Chapter V presents findings of the study and an interpretation. Chapter IV provides a summary, conclusion and recommendations, limitations of the study, and suggestions for future researches.

CHAPTER II

CONCEPTUAL FRAMEWORK

Economies and Diseconomies of size

The initial hypothesis of this research is that processing of litter is economical. Initial work shows that processing will be more economical if the processing plant is large enough to process litter from several poultry farms. Mapemba showed that as plant capacity increases from 60,000 to 120,000 tons per year the shadow price of additional capacity decreases from about $40.39 to about $38.69. Large scale production reduces unit price of materials, supplies and purchase of services from other enterprises up to a point. Mapemba found, however, that as capacity increases, the additional units of litter cost more to transport because of additional transport distance. So, with higher processing volume, the net effect of constant marginal revenue, decreasing marginal cost of processing, and increasing marginal cost of transport combined is declining shadow prices of capacity.

Greenhut also suggested that with increases in size of the plant the long run average cost (LRAC) will decrease up to certain plant size, but after that point average cost will rise. Salassi and Champagne further showed that the relationship between firm cost and output is best represented by economies of size. Economies of size is mainly concerned with the long run average cost for the industry. As the size of the plant increases, economies of size will cause the long-run average cost curve to decline. Diseconomies of size, existing over a certain range of plant sizes, will cause the long-run average cost curve to rise. The theoretical relationship between short-run average costs, long-run average costs, and firm size for poultry processing plants can illustrated in

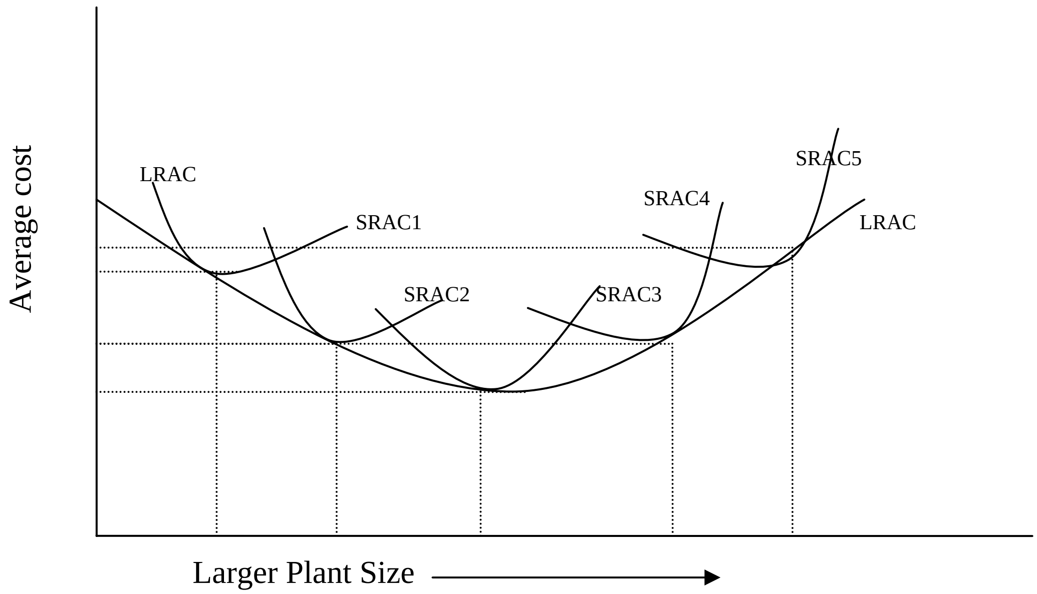

Figure II-1. Relationship of Short-run and Long-Run Average Cost and Plant Size

In Figure II.1, SRAC1, SRAC2, SRAC3, SRAC4 and SRAC5 represent short-run average costs of alternative capacities of poultry litter processing plants. These curves start to decline until full utilization of their inputs (poultry litter) for that particular capacity. After this point they tend to rise due to the law of diminishing return. The LRAC represents the long-run average cost, when plant size is allowed to vary. As capacity increases, the plant must transport poultry litter greater distances as it increases its use of this input, raising its costs of acquiring poultry litter.

Although increases in capacity tend reduce LRAC, at some point increases in capacity begin to raise LRAC. This is especially true for this particular application -- increasing capacity increases the cost of acquiring the major input.

By borrowing the concept of efficient unit isoquant from Bressler and King (pp.402-405) and analysis by Greenhut (pp 8-16) we can determine the theoretical optimum location of a single processing plant among alternative plants. In Figure II.2 a curve SS' represents a unit isoquant curve on which per-ton processing costs of plants of alternative capacities are presented. Non-transport cost includes land, labor and operating cost, which often is characterized by economies of size. Along this curve there are five possible plants (A, B, C, D and E) of various sizes (A the largest, E is the smallest) to be located in a particular location. It is assumed that all the plants are operating at maximum technical efficiency, including full utilization of capacity. The vertical axis (Y) represents transport cost per ton of litter and the horizontal axis (X) non-transport cost per ton of litter.

Plant A is located to the left of the other plants, indicating that it incurs highest transport cost and the lowest non-transport cost. Plant E is located to the right of the other plants, incurring the largest transport cost but the highest non-transport cost. Moving up the vertical axis or right on the horizontal axis increases costs; conversely, a movement towards the origin on either axis decreases cost. Curve SS' is less elastic from point C to A and more elastic from point C to E, so that a movement from A to B results in a small increase in non-transport cost but a larger decrease in transport cost. A movement from D to E, on the other hand, results in a small decrease in transport cost but a larger increase in non transport expenses. So point C on the substitution curve is a least cost solution; it is a point of unitary elasticity. This point represents the plant location that is the optimum tradeoff between transport and non-transport costs so that unit cost is minimized.

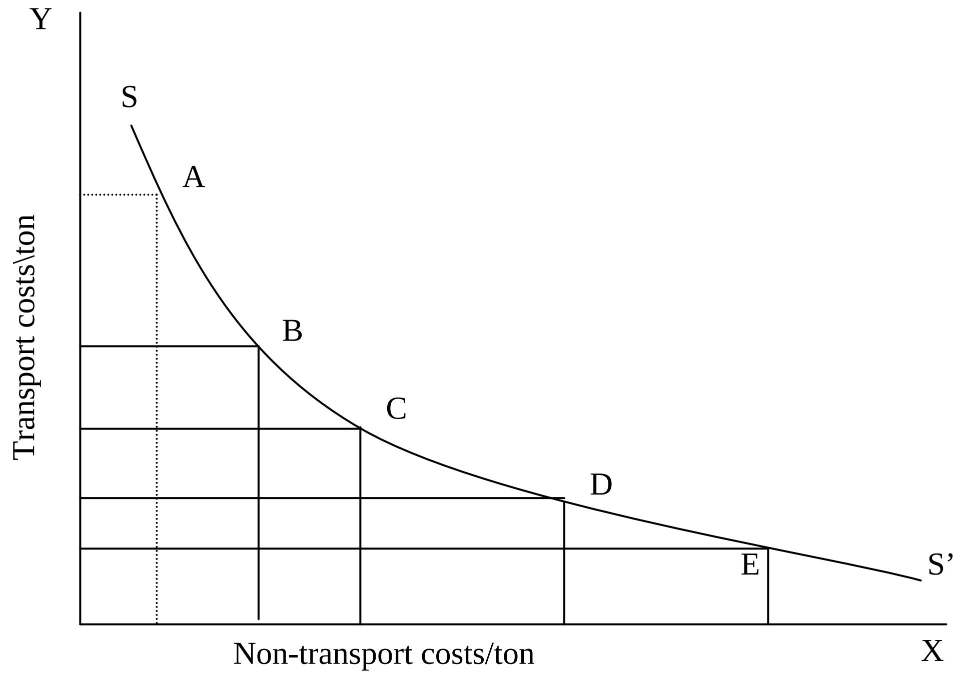

Figure II-2. Substitution Between Transport and Non-transport Costs on Efficient Unit Isoquant Curve

To illustrate, consider a processing plant to which raw materials produced in the area surrounding the plant are transported. Examples might be an ethanol plant that processes corn grown in the surrounding area, or a milk cooperative that process milk grown in surrounding dairy farms. Because of economies of size, per unit processing costs are lower when a larger amount of raw materials is processed. But to process more, the raw material inputs (corn and raw milk in these examples) must be transported from greater distances, raising per unit transport costs. The optimal point C in Figure II.2 is reached where the reductions in per unit processing costs from increasing plant capacity are offset by increasing per unit transportation costs.

Market Trade Boundary

Because of the tradeoff between transportation costs and economies of size, it may be more economical for poultry producers farther from the processing plant to export their litter to a phosphorous deficit area outside the watershed than to the processing plant. The number of producers and amount of litter that may be subject to this choice depends on how significant are economies of size and capacity utilization compared with transportation cost.

Figure II.3 shows the market area for a poultry litter processing plant. The different circles represent poultry growers at different distances from processing plant 1 and 2. The points denoted by F, G, H, I, J represent locations of producers in the plants' trade areas.

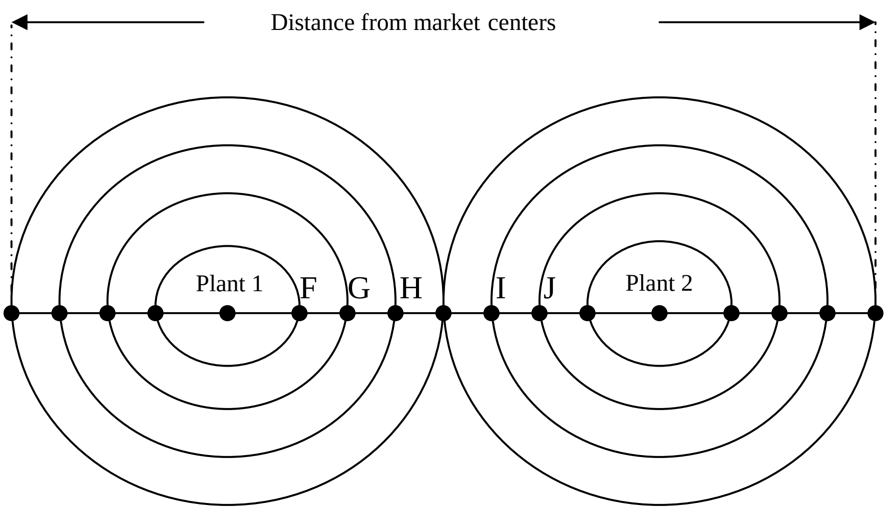

Figure II-3. Processing Plants' Market Boundaries

As Bressler and King note (pp.126-27), the boundary of a market area is where the net price (price less transfer costs) is equal to the net price for another market. In Figure II.3, assuming producers must pay for transporting litter to the processing plant, producers at F and G will prefer to sell their litter to plant 1 and producers at I and J will prefer plant 2 because the net price received is higher. Producers on the boundary (at point H) are indifferent between selling litter to either plant; their choice would depend on non-economic factors. Producers at any of the locations must choose between the net price from the plant with the highest price and the next most valuable use of the litter. (This value could be negative if the next most valuable use is paying someone to dispose of the litter. Adam and Hong describe modifications to the model when alternative use value is relevant.) The higher the value of litter for use as a fertilizer outside the watershed or the higher the net price from another processing plant the smaller the trade area for the processing plant.

If processing were the most attractive use for litter from some set of producers, it should be profitable to establish a second processing plant whose trade area boundary meets the boundary of the first plant. This would require that sufficient litter be available in the second plant's trade area to allow capture of size economies. If this condition were not met, say at the edges of the production region, it is more likely that the highest value would be achieved by transporting litter outside the watershed.

CHAPTER III

LITERATURE REVIEW

The purpose of this review is to describe the most common use of poultry litter as fertilizer; to summarize alternative ways to dispose of litter in areas where its use as fertilizer would result in high level of Phosphorous (P) loading; and to show the implication of policies and strategies implemented to control the effect of P loading.

Poultry Litter Use as Fertilizer

Since poultry litter is rich in nutrients and organic matter, it can be used for a variety of purposes such as cattle feed ingredients, and as a bio-fuel source (Peel). As explained by Karelen, Russel and Mallarino, the land application of raw litter is simple and inexpensive, and the litter is valuable as a fertilizer. Zhang, Hamilton and Bitton have also commented on the importance of poultry litter as a low cost fertilizer, which could return nutrients and organic matter to the soil, building soil fertility and quality. In their research in southeastern Oklahoma, they estimated average forage yield and protein content of 4.82 tons/acre and 12.6% respectively, in Bermuda grass, from application of N from poultry litter as compared to 3.44 tons/acre of forage yield and 8.8% of protein obtained from commercial fertilizer. But some studies indicated that there is a trade-off between the use of poultry litter and urea nitrogen depending on soil fertility, the yield response to litter application and the relative price of nitrogen and litter. An Arkansas study indicated that it is uneconomical to use fresh or composted litter at lower target yields of rice. Higher yield can be achieved by application of nitrogen in addition to fresh litter. (Govindasamy and et al).

According to Carpenter's (1992) estimation, 90% of all poultry wastes are applied directly to land. This application is generally to meet the nitrogen (N) needs of crops. This leads to over-application of P due to the lower N to P ratio in litter compared to that required by most crops. Accumulation of P in soil creates a threat of surface runoff of P into water sources. Concentrated poultry production may result in high ratios of poultry litter to available nearby cropland, and it may be applied at a higher rate than required by the crops (Bosch and Napit). T.R. Miles Technical Consulting, Inc., in a contracted study to the Northeastern Regional Biomass Program, has reported that nutrient-rich run-off from agricultural lands has been identified as a potential cause of pfiesteria in the Chesapeake Bay and its tributaries.

Land application of broiler litter in eastern Oklahoma and western Arkansas has become a major pollution concern since the 1980s. Litter is concentrated because its transportation cost is high. In particular, eutrophication of lakes Eucha and Spavinaw has been blamed on high phosphorous loading in the watershed attributed to land application of litter produced by intensive poultry production (Storm et al.).Water from eutrophicated lakes is not suitable for drinking due to bad taste caused by algal blooms. Moreover, the eutrophication reduces recreation value of these lakes.

Poultry Litter Disposing Alternatives

Several practices have been proposed to reduce phosphorous loading. According to Zhang, Hamilton and Britton, five steps should be followed to assure proper amount of litter utilization. These steps are: 1) determine crop nutrient requirements; 2) determine nutrient content of litter; 3) determine the fraction of litter nutrients available to the crops in the first year of application; 4) determine litter application rate to supply crop nutrient needs; 5) determine supplemental nutrients needed for maximum crop growth. As Bullard and Britton pointed out, the Oklahoma Cooperative and Extension Service recommends a P application rate of 200 lb/acre. But as many studies have indicated, application of manure as fertilizer in eastern Oklahoma is beyond the land's saturation point. Ancev, for instance, has estimated the socially optimum P loading level to be between the range of 23,000 to 26,000 kilogram per year but the Soil and Water Assessment Tool (SWAT) result of Storm et al showed that the P loading of lake Eucha has already reached 47,600 kg per year. This same study has indicated that there is a high correlation between phosphorous loading and litter application.

Ancev recommended application of litter only to land that is less susceptible to phosphorous runoff. In his study, a Soil Test Phosphorous (STP) index is used to represent the amount of fertilizer or manure needed to obtain optimum yield. At this index level the soil has sufficient phosphorous for plant uptake. Phosphorous application above this amount may run off. This STP recommendation has not been adopted in the Eucha Spavinaw watershed, particularly in the Arkansas side of the watershed where more poultry production occurs, resulting in high phosphorous levels in the soils.

An alternative management practice is applying alum (aluminum sulfate) to either the litter or the land. Alum has the potential to tie up soluble phosphorous and transform it into more stable aluminum phosphate compounds that are insoluble and hence are not readily available for plant and algae uptake (Moore and miller). The alum product is added to litter in the poultry house in alum-to-litter ratio of 1-to-10 (Ancev) It can also be applied directly to land. Alum ties up phosphorous, thereby significantly reducing the potential for soluble phosphorus runoff once the litter is applied to agricultural land. Although this practice is beneficial, it may not be sustainable because cost of litter management is very high.

Davalos, Roux, and Jimenez indicated the importance of poultry as a natural fuel source of power generation. Their study, performed in Spain, showed that high combustibility and power generation capacity can be obtained only from dry poultry litter. Poultry litter with water content of less than 9% could be combusted without extra fuel and could be effectively used as a fuel to generate electric power. A gradual increase in moisture content can require extra fuel; and moisture increase above a certain level can completely reduce the massic energy combustion. As it has been clearly pointed out by Kelleher et. al. fuel cost, capital cost and environmental and regulatory policies are the limiting factor in making future decisions using this disposal technique.

To counteract the potential negative water quality impact of litter application, composting it could limit N leaching to ground water through formation of more stable organic components and reduce the volume by about 50%. Composting is an aerobic degradation of biodegradable organic waste. The composting process takes 4-6 weeks to reach a stabilized material. This stabilized material is odorless and fine texture with low moisture content and can be used as organic fertilizer. Moreover, it is easy to handle and pathogen free. The economic analysis of Vervoort and Keeler, however, indicated that the fertilizer value of Composted Broiler Litter (CBL) was -$2.93 per metric ton and that of Fresh Broiler Litter (FBL) was $5.78 per ton. So this practice is a much more expensive disposal alternative than use of fresh broiler litter. Also, they concluded that the fact that CBL produces less P runoff than FBL could make it attractive only if environmental controls are imposed on pasture producers and pastureland expansion does not keep pace with broiler production. A related study performed by Tyson indicated that only 10% of the total N in the composted litter was plant available in the first year, compared to 30-50% in the fresh broiler litter. Kelleher et al. also revealed that the disadvantages of composting are loss of nitrogen and other nutrients, equipment cost and labor, available land, etc.

Some have proposed transporting the litter out of the region to areas where its value as fertilizer is higher. According to Cochran and Govindasamy (1995b) in Northern Arkansas, transportation of litter from areas of high poultry concentration to areas with lower potential for contamination may not only improve the surface and ground water but may also enhance the productivity of disturbed soil in the delta region. For such transportation to be economical, the value of marginal product of litter as a soil amendment in row crop production must exceed the sum of transportation costs and the value of marginal product as a fertilizer in local forage production.

The result of their study showed that 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 transport the litter to the delta area. Based on this result it is found that the optimum situation is to transport the entire litter production from three out of four source regions, with the exception being one region where opportunity cost is higher than transport cost. But this finding depends on assumptions such as crop prices at $0.071/pound of rice, $0.606/pound of cotton and $5.858/bushel of soybeans, cost of truck transport of litter at $0.10/ton/mile, cost of handling and spreading of litter at $11.42/ton and $3.67/acre respectively.

A similar study by Bosch and Napit compared the cost of transferring surplus litter to deficit areas with its economic value as a fertilizer. The litter value as fertilizer is estimated by determining the amount of litter application required to obtain nutrient (N, P & K) levels equivalent with commercial fertilizer. Their study in Georgia showed that the highest cost of shipping surplus litter to deficit counties at average hauling distance of 50 miles is $18.86/ ton as compared to $24.33/ton, the value of poultry litter application as a fertilizer. This study indicated that the estimated fertilizer value of litter exceeds the cost of obtaining, delivering, and applying litter to cropland. Such transfers would result in substitution of poultry litter for commercial fertilizer nutrients and thereby potentially reduce P loading and sustainability of the poultry industry. A study by Parker to assess the costs of implementing the Maryland Water Quality Improvement Act 1998 has also indicated that the net cost significantly rises if all excess poultry litter is composted or converted to energy instead of applying it to land. But the net change to industry if all excess litter is transported out of the region is estimated to be positive. But many researchers, including Poudel and McIntosh and Cochran and Govindasamy, agree that due to the low nutrient content of litter and thus the high volume required for larger yield, it is not economical to transport a large quantity of litter long distances for use as a plant nutrient.

In some studies cattle feed is an alternative market for poultry litter. Processing of poultry litter as cattle feed can be done by ensiling it with corn or sorghum, by forming pellets or simply by stacking litter for at least 20 days before mixing with other feed. Poudel and McIntosh estimated that with a prevailing price of $25.00 per ton of broiler litter suitable for cattle feed in Georgia, a farmer could achieve a 112 percent higher net return when the ration contains poultry litter than when the ration consists of a traditional combination of winter annuals and grains. This high return is mainly because it reduces the total cost of cattle feed. But due to its high uric acid content there are regulatory restrictions to feeding broiler litter to dairy cows, calves below 400 pounds and stockers less than 15 days before slaughter.

Processing the litter to produce electricity and saleable fertilizer products is another alternative practice recommended by many researchers. According to a T.R. Miles technical Consulting Inc. report, energy conversion can provide steam and electricity while providing a means of concentrating litter P and K in the form of ash that can be transported easily to other locations for use as fertilizer. Under recently passed environmental legislation restricting land application of poultry litter, technologies that can utilize 280,000 tons of litter per year to produce 25 MW of energy capability are available to energy consumers of lower Delmar peninsula. Besides providing energy, the proposed technology will create new jobs in hauling and at the energy facilities; provide new income for poultry owners; concentrate the fertilizer value of litter in an ash form for use outside the local region; and significantly reduce nutrient run-off into local rivers and the Chesapeake Bay.

Direct combustion, anaerobic digestion and other technologies could be used to process the litter into salable energy and fertilizer byproducts. According to Kelleher et al., direct combustion is an incineration of poultry litter using efficient combustion facilities with a sophisticated gas cleanup, which produces energy and reduces the waste to an inert residue with reduced pollution. The product of such combustion can be used for space heating of poultry houses and power generation. The ash residue produced is stable, sterile, easier to handle and transport and more marketable as an organic fertilizer than conventional poultry litter. However, combustion is influenced by conditions of fuel supply, moisture content of poultry litter, temperature, etc. and economic limiting factors such as plant capital investment, fuel cost and fuel price stability.

Anaerobic digestion, on the other hand, is degradation and stabilization of an organic material under anaerobic conditions by microbial organisms. This leads to the formation of methane and inorganic products including carbon dioxide. The methane produced in this process can be used as a fuel for boilers as a replacement for natural gas or fuel oil and can also be fired in engine generators to produce electricity. The residual sludge is stable and can be used as a soil fertilizer. Investigation by Kheller et al. showed that excessive level of ammonia and/or high pH or temperature levels could inhibit methane production. To reduce those effects, expensive additives such as phospherite are used. They stress that for this process to be financially viable, a disposal fee to farmers and/or the sale of digested solid effluent as an organic fertilizer is important.

Lichtenberg, Parker and Lynch have also investigated the economic feasibility of electricity generation. Their study indicated that a firm using poultry litter for wholesale electric power generation could not pay a positive price for poultry litter and remain profitable without a renewable energy tax credit. Electric power generators could not afford to pay a positive price for litter because establishment and operational cost of the technology is very high. In a similar study, Mapemba showed that, the returns to investment are directly or indirectly affected by the location of the processing plants, number of plants in the poultry production region, size (capacity) of the processing plant, and quantity of methane gas produced per ton of litter.

Implication of Policies and Strategies

The other important aspect of this review is a discussion of different policies and strategies implemented to prevent Phosphorous loading from application of poultry litter. Govinadasamy and Cochran (1995a), for instance, developed an economic model of Phosphorus loading to analyze the policy implications of the Cooperative Extension Service’s (CES) recommendation on quantity restriction on litter application. The US Cooperative Extension Service (CES) recommends that no poultry litter be applied if STP concentrations exceed 300 pounds per acre, irrespective of the marginal costs and benefits associated with one more unit of litter application on the piece of land. The economic model calculated the optimum solution with unconstrained maximization (without P restriction), with constrained maximization (with P restriction) and with P amount and application rate constraint. To formulate the mathematical programming model specific soil units were aggregated into manageable soil classes based on their physical characteristics for yield response. The optimal solutions indicated that marginal value for litter application were $2.70 with unconstrained maximization, $17.66 with a phosphorous constraint and $20.47 with both a phosphorous constraint and application rate consistent with the difference in marginal value between the most valuable and the least valuable soil type. The existence of such a difference suggests that more acres can be brought into environmental regulation by adopting a marketable permit system.

In a similar study Govinadasamy and Cochran (1998), developed a hypothesis that although there are numerous policy tools to control land applications of poultry litter, only some are suitable for a given environment. To prove their hypothesis, they reviewed policy scenarios such as (1) a per ton litter tax, (2) a land tax on litter application, (3) a quantity restriction on litter applications and land treated with litter, and (4) a permit system to control litter applications and land treated with litter. The results indicated that a per ton tax on litter applied could achieve the same level of litter control as that of a land tax on litter applications at lower tax rate.

Paudel, Adhikari and Martin used data collected from 29 counties in northern Alabama to assess the maximum amount of litter that can be utilized in crop producing counties located near broiler producing counties. For such determination, the phosphorus consistent rule was applied. A transportation model was developed to find the most cost efficient routes for litter transfer to meet the total nutrient demand of four major crops grown in the area. The study used the Alabama Cooperative and Extension Service (ACES) recommended rate of commercial fertilizer for corn and Cotton to be 60:40:40 and 120:40:40 per lbs/acre, respectively (N,P,K). If chemical fertilizer were applied to meet this need, it would cost $35.60 per acre for corn and $53.60 per acre for cotton. But according to the model they developed, assuming that 75% of P in the applied litter is available, loading cost is $0.50/ton, hauling rate is $0.10/ton and spreading cost is $3.50/ton, use of broiler litter at a recommended rate will provide cost savings of $18.52 per acre. This indicated that litter could be economically transported up to 164 miles from the production facilities. This strategy has its own limitation. Litter is applied based on the phosphorous consistent rule and deficit nitrogen needs to be met from chemical fertilizer, so the change in the price of commercial fertilizer has an effect on the amount and cost of litter utilization. For instance, when the price of chemical fertilizer increases from the current level, the total cost of meeting the nutrient need increases proportionately.

Paudel and McIntosh studied the economics of poultry litter utilization and optimal environmental policy for phosphorous disposal in Georgia. In their study the impact of imposing a standard tax and permit system for controlling the total amount of poultry litter in Georgia was also examined. For this assessment a profit maximization model that combined litter as nutrient and cattle feed was used. The study result showed that the permit system is a superior policy tool to achieve the target level of utilization at minimum resource costs. That conclusion is similar to that of the earlier study by Govinadasamy and Cochran.

Parker studied the impact of the Maryland Water Quality Improvement Act 1998 on agricultural nutrient users and poultry growers. This act requires all crop growers to implement a nutrient management plan that considers both nitrogen and phosphorous utilization and application rate. The study considered the economic impact of implementing three litter utilization practices (composting, energy conversion and transporting out of the region) as alternatives to land application. The result showed that net cost rises significantly if all excess poultry litter is composted or converted to energy instead of applied to land. But the net change to industry if all excess litter is transported out of the region is estimated to generate positive result.

Ancev also has drawn policy implications from his study. He pointed out that a single "command and control" based (STP policy alone) is ineffective in reducing the phosphorous loading and is economically inefficient. Policies that encourage overgrazing management such as reducing stocking rates and better nitrogen fertilizer would be effective and efficient for reducing phosphorous loading. Policies that also encourage site-specific conversion of row crops to hay (or another crop less susceptible to phosphorous runoff), would also contribute significantly to reduction of phosphorous loading. Land use conversion must be initiated through an incentive scheme involving taxes or subsidies for the individual land users, since the conversion is not beneficial from the perspective of private land users. Moreover, policies to encourage agricultural producers to adopt litter management technology (such as treating litter with alum) should be considered. In the short-run, when land use conversion is not attainable, transporting litter out of the watershed, or some other form of litter utilization within the watershed would be required. To encourage transportation of litter out of the watershed tax incentives and/ or subsidies are recommended.

The study by Cochran and Govindasamy (1995b) study in northern Arkansas also pointed out that without government intervention, litter from the region of greatest concentration (Fayetteville) is the least likely to be transported. One of the reasons is the high cost of transportation due to the bulky nature of litter with limited nutrient content, odor problems, storage availability and absence of an organized market for litter. So possible government interventions include policies such as quantity restriction on litter use in northern Arkansas, a tax on litter use or land treated with litter in areas of high potential for contamination, and/or a subsidy for transportation.

CHAPTER IV

PROCEDURES AND DATA SOURCES

Procedures

The purpose of this study is to minimize the cost of reducing specified amounts of litter from a watershed by processing it, by transporting it from the watershed to phosphorus deficit area, or both. The study was conducted in three different Scenarios. Scenario I analyzed reduction of poultry litter in Oklahoma with an assumption that no processing plant is established. Continuous variables were used to determine the quantity of litter transported from each poultry grower to each selected wheat-and/or forage-growing county outside the watershed. A linear programming model was used to determine the optimum solution.

Scenarios II and III examined the combined alternatives of establishing processing plants and transporting some amount of poultry litter outside the watershed. Scenario II included only Oklahoma poultry farms, while Scenario III included poultry farms from both Oklahoma and Arkansas. Binary variables were used to select or not select a particular location and processing plant capacity. Mixed integer programming procedures were used to find the optimum solution.

Since the assumptions about profitability of processing plants are projections and have not been tested, the model results are tested for sensitivity to an alternative assumption. The alternative assumption is that rather than achieving the full expected profitability, the processing plant attains only 50% of that expectation; for example, if processing yields of fertilizer are lower than predicted, if wholesale electricity or fertilizer yields are lower than predicted, or if wholesale electricity and fertilizer prices are lower than predicted, or if the "green energy" tax credit (currently 1.8¢/kwh) were not available.

The model choice variables were quantities of litter transported from each farm to each processing plant and processed, capacity of each processing plant that is built, and quantity of litter transported from each farm to each of several phosphorous deficit counties. The model selected one of five plant capacities for each prospective plant location: 100,000, 200,000, 300,000, 400,000 and 500,000 tons per year of litter processing capacity. Alternatively, the model could choose to build no plant at a particular location. Binary variables were used to model these choices. Continuous variables were used to determine the quantity of litter transported from each farm.

Basic assumptions about the model

1) The model solution reflects costs and returns for a one year planning period;
2) The model selects either no processing plant or one plant with one of five possible processing capacities for each location;
3) The processing capacity of the plants is constant over the year period and poultry litter not processed in a given time period remains in the watershed;
4) The site chosen for processing plants has adequate water supply and transportation facilities and is located at sufficient distance from the neighbors;

5) Fertilizer and electricity produced are priced at the plant site. Thus the cost of transporting these products is covered by the purchasers;

6) Poultry producers are organized into a cooperative to maximize their benefits. As part of their contribution to the processing plant, they provide a specified supply of litter free of charge;

7) Crop and forage growers in phosphorous deficit regions are willing to pay for poultry litter to supplement their farms' nutrient requirement.

The objective function of the mixed integer mathematical programming model is given as:

$$\text{Min Z} = \sum_{i=1}^{9149}\sum_{j=1}^{5}\sum_{p=1}^{5} C_{ij} X_{ijp} + \sum_{i=1}^{9149}\sum_{e=1}^{11} C_{ie} X_{ie} + \sum_{i=1}^{9149}\sum_{j=1}^{5}\sum_{p}^{5} PC_{p} X_{ijp} + \sum_{j=1}^{5}\sum_{p=1}^{5} FC_{jp} Y_{jp} - \sum_{t=1}^{9149}\sum_{j=1}^{5}\sum_{p=1}^{5}\sum_{t=1}^{3} X_{ijp}\alpha_{t} R_{t} - \sum_{i=1}^{9149}\sum_{j=1}^{5}\sum_{p=1}^{5} X_{ijp}\beta_{g} R_{g} \qquad (4\text{-}1)$$

Where:

Z = Total transportation, processing and annual fixed costs

i = Location of poultry farms at Eastern Oklahoma and poultry houses at Western Arkansas (*i* from 1-8225 are poultry houses in Arkansas and from 8226-9149 are poultry farms in Oklahoma)

j = Locations of different processing plants (site1, site2, site16, site22 and site33)

p = Size of processing plants (100K, 200K, 300K, 400K and 500K- tons)

e = Phosphorous deficit counties outside the water shade (e = 1,2, 3…..,11)

t = Type of fertilizer (N, P, or K)

X_{ijp} = Quantity of poultry litter transported from *i* to plant size *p* at location *j* (tons)

C_{ij} = Cost of transporting litter from farm *i* to plant location *j* ($/ton)

C_{ie} = Cost of transporting litter from farm *i* to county *e* ($/ton)

X_{ie} = Quantity of litter transported from farm *i* to county *e* (tons)

PC_p = Cost of processing one ton of poultry litter at plant size *p* ($/ton)

FC_{jp} = Annual fixed cost of building and operating plant size *p* at location *j* ($)

$Y_{j_1 p}$ = Binary variable for building plant size *p* at location *j*, equal to 1 if plant is built, zero otherwise

α_t = Conversion coefficient from poultry litter to fertilizer of type *t* (lbs / tons of litter)

R_t = Unit price of fertilizer type *t* ($/lb)

β_g = Conversion coefficient from poultry litter to electricity (kwh/ton of litter)

R_g = Unit price of electricity ($/kwh)

F_{jpt} = Quantity of fertilizer type *t* produced at location *j* in plant size *p* (lb)

G_{jp} = Quantity of electricity produced at location *j* in plant size *p* (kwh)

ϕ = Proportion of processing plant capacity used (%)

$PCAP_{jp}$ = Litter utilization capacity of processing plant size *p* at location *j* (tons)

$FCAP_{jp}$ = Fertilizer production capacity of processing plant size *p* at location *j* (lb)

$GCAP_{jp}$ = Electricity production capacity of processing plant size *p* at location *j* (kwh)

L = Minimum amount of litter to be removed from the watershed, either by processing or transporting, outside the region (tons)

The objective function is minimized subject to the following constraints:

$\sum_{i} X_{ijp} - \phi PCAP_{jp} Y_{jp} \leq 0$ (Total amount of litter to be transported from the source location *i* to the plant size *p* at location *j* is less than or equal to its utilization capacity) (4-2)

$\sum_{i} X_{ie} - D(e) \leq 0,$ (the total amount of litter to be transported from all location *i* to external region *e* is less than or equal to the amount demanded) (4-3)

$(\sum_{j} X_{ijp} + \sum_{e} X_{ie}) - S_i \leq 0,$ (total amount of litter transported from source location *i* to all locations *j* and *e* is less than or equal to the supply at source *i*) (4-4)

$F_{jpt} = \sum_{i} X_{ijp} \alpha_t \leq \phi FCAP_{jp} Y_{jp},$ (Total annual fertilizer (F) produced at a processing plant size *p* at location *j* is less than or equal to its processing capacity) (4-5)

$G_{jp} = \sum_{i} X_{ijp} \beta_g \leq \phi GCAP_{j_1 p}$ (Total annual Electricity (G) produced at a processing plant size *p* at location *j* is less than or equal to its processing capacity) (4-6)

$\sum_{i}\sum_{j}\sum_{p} X_{ijp} + \sum_{i}\sum_{e} X_{ie} - L \geq 0$ (Total amount of litter transported from all sources to all destinations both inside and outside the watershed is greater than or equal to the minimum amount of litter L that must be removed from the region) (4.7)

$\sum_{p=1}^{5} Y_{jp} \leq 1$ for all j, (No more than one plant is established in one location) (4.8)

$\sum_{j=1}^{5} Y_{jp} \leq 1$ for all p, (No more than one location is assigned for each plant) (4-9)

$X_{ijp}, X_{ie}, F_{jpt} \ G_{jp} \geq 0$ (Non negativity conditions) (4-10)

For each simulation, the optimum objective value Z was divided by the total volume of litter processed and transported $\sum_{i}\sum_{j}\sum_{p} X_{ijp} + \sum_{i}\sum_{e} X_{ie}$ to obtain the per ton cost of removing litter from the watershed.

Data Sources

Required data for the model include: 1) location of each poultry farm in eastern Oklahoma and western Arkansas; 2) quantity of poultry litter produced at each farm; 3) quantity of litter that could be processed at each plant; 4) quantity of litter that could be used as fertilizer at each P-deficit county outside the watershed; 5) Litter transportation cost per ton; 6) variable litter processing cost for each processing plant; 7) Fixed cost of processing at each capacity; 8) litter-to-fertilizer and litter-to-electricity conversion rates; 9) prices of fertilizer and electricity; 10) capacity utilization rates of processing plants; and 11) minimum amount of litter to be removed from the watershed.

Location of poultry production units and quantity of litter produced by each poultry farms was obtained from the Oklahoma Department of Agriculture. Production units in Oklahoma are farms. For each of the 924 farms the number of birds of each type (broilers, pullets, layers and turkeys) was obtained along with the geographic location (section) of the farm. The centroid of the section in which the farm is located was used as the GIS coordinate for the farms.

Production units in western Arkansas are individual poultry houses rather than farms. Neither number of birds per house and amount of litter produced is available for the 8,225 houses. Thus, it is assumed that amount of litter produced in each house is the same as the average amount produced in Oklahoma house, estimated to be about 120 tons per year.

Possible sites for constructing poultry litter processing plants were provided by Production Specialities, Inc. (PSI), a partner in the proposed enterprise and owner of the processing technology. These sites are designated as site1, site2, site16, site22, and site33 (Appendix A) and are situated along the railroad in the northeastern part of Oklahoma. The exact names of these locations are not specifically provided for confidentiality reasons. The shortest distances in miles from all poultry farms and houses to these locations were calculated by Dr. Allen Finchum of Geography Department Oklahoma State University, using GIS software.

Conversion ratios for amount of electricity and N, P, and K produced from each ton of litter, variable litter processing costs, and fixed costs of processing plants were also provided by PSI. The conversion ratios have not been independently verified, but will be compared with conversion ratios achieved with a demonstration plant now under construction.

The potential demand for poultry litter by phosphorous-deficit regions was calculated using data obtained from the National Agricultural Statistics Service (NASS) and information provided by Dr. Hailin Zhang of the Soil, Water, and Forage Analytical Laboratory of Oklahoma State University.

Data Conversions

Following Mapemba, the amount of poultry litter produced by each Oklahoma poultry house was calculated by multiplying the number of birds of each type by the amount of dry manure produced by the type of bird per year, as estimated by Sims et al. They estimated that broilers produce 4.9 kg dry manure per year, layers produce 7.0 kg dry manure per year, pullets produce 2.7 kg per year and turkeys produce 10.9 kg per year. Because it is believed that the non-manure materials in poultry litter make up 20% of its weight, the dry manure weights are adjusted upward by dividing by 80%. In order to calculate the average number of tons of litter produced per poultry house so that the Oklahoma average can be applied to Arkansas, the following formula is used:

Average litter per house = OK average dry manure/farm (kg) *OK farm/ average number of houses * 1.2 (for dry manure-to-litter adjustment) * 2.2 lb/kg /2000 lbs/ ton.

Economies and Diseconomies of Size

Mapemba found that average transportation costs of poultry litter increases with increased plant capacity. This is because as the size of the plant capacity increases, the additional litter required must be transported from farms located farther away from the plant. This is a diseconomy of size. On the other hand, Mapemba also noted that processing cost per ton of litter decreases with increased plant capacity. This is an economy of size. To find the best tradeoff between these competing factors, the model selects from five processing capacities (plus building no plant at all), with associated per unit transport costs for each potential plant location.

For poultry litter produced at or near the trade area boundary of one of these plants, it might be more economical to transport it out of the watershed to a phosphorous deficit area. Supporting this possibility, Bosch and Napit found that application of poultry litter to land used to produce hay and grain has a value between $22 to $24.33/ton while the estimated cost of transporting litter to an average distance of 50 miles ranges from $16.9/ton-$18.86/ton. Using the Bosch and Napit cost of $12.22/ton for obtaining and land applying of litter, and adding it to our average transport cost of $13.00-20.00/ton, the average application cost for Oklahoma is estimated to be $25.00-32.00/ ton.

Potential Poultry Litter Demand Areas

For this study, six wheat-producing and five hay-producing nutrient-deficit counties were selected from central, north-central, and eastern Oklahoma. Potential poultry litter demand for these counties was determined by multiplying the 2003 estimates of harvested wheat and hay acres by the recommended litter application rate for each county and each type of land. This recommended rate was provided by the Soil, Water, and Forage Analysis Laboratory of Oklahoma State University.

Table IV-1. Potential Poultry Litter application to Alfalfa Hay Acres in Selected Oklahoma Counties

Northeastern OK Counties	Town/ City	Acres	Recommended application Rate (tons of litter /acre)	Total amount to apply (tons)	Value less application cost ($/ton)
Nowata	Nowata	3,000	1.9	5,700	8.78
Osage	Pawhuska	5,000	1.6	8,000	7.47
Ottawa	Miami	600	1.3	780	9.88
Wagoner	Wagoner	500	1.5	750	9.88
Rogers	Oologah	500	1.8	900	9.69
Washington	Dewey	1,000	1.3	1,300	7.28
Total		10,600		17,430	

Table IV-2. Potential Poultry Litter application to Wheat Acres in Selected Oklahoma Counties

North Central and Central OK Counties	Town/ City	Harvested (Acres)	Recommended Application Rate (tons of litter /acre)	Total Amount to Apply (tons)	Value less application cost ($/ton)
Alfalfa	Cherokee	225,000	0.4	90,000	8.58
Garfield	Enid	330,000	0.1	33,000	8.58
Grant	Medford	310,000	0.2	62,000	8.58
Canadian	Elreno	165,000	0.1	16,500	8.58
Kingfisher	Kingfisher	190,000	0.1	19,000	8.58
Total		1,220,000		220,500	

*Litter application for pasture is based on P and for wheat is based on N requirement estimated for crop year 2003 based on Oklahoma Soil Test Interpretation and Fertilizer Decision Support System.

The nutrient recommendation for wheat acres is based on the amount of N recommended and for pasture acres is based on the amount of P recommended. But according to the soil test for some of the wheat producing counties, at the recommended rate where the N requirement is met, the P amount will be in excess of the amount recommended. For those counties, in order to avoid excess application of P, this study chose the lower application rate. The remaining small amount of N deficit is assumed to be supplemented from commercial fertilizer.

Poultry Litter Transportation Cost

The cost of transporting poultry litter includes cleanout, loading, hauling and unloading costs. Following Mapemba,

$$C_{ij} = [\alpha T_{ij} + \beta (D_{ij} - 3) N_{ij}] / T_{ij} \quad \text{Where,}$$

C_{ij} = The cost per ton of hauling poultry litter from source *i* to destination *j*;

α = A constant representing a uniform loading charge (in current practice, this charge includes the first three miles of hauling);

T_{ij} = Total amount of litter transported from *i* to *j*;

β = A constant representing the cost of hauling litter per mile per 25-ton truckload;

D_{ij} = Hauling distances in mile from each source *i* to each destination *j*;

N_{ij} = Number of 25-ton truckloads hauling litter from *i* to *j*;

The calculations done in Excel to get the final unit transportation costs were as follows:

a) The number of tons of litter per farm was multiplied by α to get the total loading cost per farm;

b) The amount of litter per farm in tons is divided by 25 tons per truckload to obtain the number of 25-ton truckloads to be hauled from each farm;

c) Since the loading cost includes three miles of travel, three miles is deducted from the distance of each farm to the destination locations;

d) The distance calculated in c) was multiplied by β to get the travel cost per truckload from the farm to the processing plant;

e) The travel cost obtained in d) was multiplied by the number of 25-ton truckloads obtained from b) to get the total cost of hauling one year's production of litter from each farm;

f) The travel cost from e) was added to the loading cost from a) to get the total cost of loading, and transporting and unloading litter from each farm to the destination sites. This sum is the " total litter transportation cost" for each farm;

g) Finally, the total litter transportation cost per farm found in f) was divided by the quantity of litter in tons produced in each farm to get transportation cost per ton per farm.

h) The transportation costs obtained above (C_{ij}) were used in the mathematical programming model;

Following Mapemba and Allen a loading charge of $5.00 per ton of litter and hauling cost of $3.00 per mile per 25 ton truckload were used as constants in this study. No backhaul possibilities were considered.

Minimum Amount of Litter to Be Removed

Preliminary studies estimate that for a processing plant to operate profitably, a minimum of 100,000 tons of litter per year should be utilized. Since the Oklahoma poultry industry produces approximately 339,360 tons of litter per year, all Scenarios in this study are analyzed by setting the alternative minimums amount of litter that must be removed at 100,000, 250,000, and 300,000 tons.

Quantity of Electricity

PSI also provided estimates of technical coefficients, including quantities of electricity and N, P, and K fertilizers produced from one ton of litter and equipment and operating costs. Using the information from PSI, quantity of electricity (Q_E) is determined by dividing the British Thermal Units (BTU) of energy available from litter (4,600 BTU/lb of litter) by the amount of energy needed to generate one kwh electricity (3,412 BTU/kwh). This number was multiplied by the efficiency of electricity conversion (12.15%). The conversion equation is:

$$Q_E = [(4{,}600\frac{BTU}{lb})/(3{,}412\frac{BTU}{kwh})]*(2{,}000\frac{lb}{ton})*0.1215$$

$$= 1.3482\frac{kwh}{lb}*2{,}000\frac{lb}{ton}*0.1215$$

$$= 327.61\frac{kwh}{ton}$$

Fixed Cost

The fixed equipment costs of the processing plant include annual capital cost, maintenance cost, taxes and insurance expenses. The annual capital cost is interest on the proportion (assumed to be 50%) of total capital investment to be financed from bank loans calculated with a compound interest of 8% over a 20-year expected lifespan. Management and administration costs were assumed to be fixed for all plant capacities. Maintenance cost, tax and insurance were assumed to be 2%, 1% and 1% of the total capital investment, respectively. The details of these costs for processing plants of varied capacities are presented in Table 4.3.

Table IV-3. Annual Fixed Costs for Alternative Plant Capacities ($)

Plant capacity	100K tons	200K tons	300K tons	400K tons	500K tons
Annual Capital Costs	509,261	771,896	984,494	1,169,975	1,337,588
Mgmt and Admin	200,000	200,000	200,000	200,000	200,000
Maintenance	250,000	378,929	483,296	574,349	656,632
Taxes	100,000	151,572	193,318	229,740	262,653
Insurance	100,000	151,572	193,318	229,740	262,653
Total FC	1,159,261	1,653,968	2,054,426	2,403,803	2,719,526

Processing cost

Processing costs include chemicals for boiler water treatment and cooling; 1.4 operators at pellet mill, hammer mill and drier train; and electricity for gasification purpose. It is assumed that these costs do not vary with quantity of litter processed.

To arrive at the unit processing cost of each plant capacity, the total variable cost was divided by the amount of litter utilized by the plant. The processing plant was assumed to operate at 90% capacity utilization, allowing for scheduled downtime and inefficiencies. These costs are presented in table 4.4.

Table IV-4. Annual Processing Costs for Alternative Plant Capacities ($)

Plant Capacity	100K tons	200K tons	300K tons	400K tons	500K tons
Chemicals	60,000	72,000	216,100	288,100	360,100
Operator Labor	744,567	1,277,700	1,703,600	1,916,600	2,342,500
Electricity	140,700	246,260	316,600	351,800	422,200
total Variable cost	945,267	1,595,960	2,236,300	2,556,500	3,124,800
Total litter used (90%)	**90,000**	**180,000**	**270,000**	**360,000**	**450,000**
Processing cost/ton	10.50	8.87	8.28	7.10	6.94

Prices of Electricity and Fertilizer

Using information from United States Department of Agriculture (USDA/ ERS) Prado estimated the price of fertilizer. Because the fertilizer that will be produced by processing poultry litter is not in the form typically sold commercially, the value of N, P, and K were estimated from their value as components of more commonly used forms. Hence the prices of fertilizer provided in urea, super phosphate and potassium chloride were used for this estimation. The N content in the urea is 44%, the P content in supper phosphate is 46% and the K content in potassium chloride is 60%. These percentages and the prices of urea, super phosphate and potassium chloride were used to calculate price per pound of N, P, and K from 1983-2003. Historical monthly commercial electricity prices were taken from the United States Department of Energy and from Gill et al. A regression analysis was conducted for each of these to identify any price trends, and to estimate variability of prices. The final average price estimated by the regression analysis was $0.04/kwh for electricity; $0.18/pound for N; $0.18/pound for P and $0.09/pound for K. No trend was statistically significant.

CHAPTER V

STUDY RESULTS

The results of this study are discussed based on the output of three Scenarios of the objective function.

Scenario I: Transporting Oklahoma Litter outside the Watershed

For Scenario I, the results indicate that 100,000 tons of litter could be transported outside the watershed at a cost of $15.70/ton. Of the 924 poultry farms in Oklahoma, 248 (26.8%) would send their litter outside the watershed. Most of the litter shipped (86.9%) is from Delaware, Ottawa, Haskell, Cherokee and Mayes counties (Table V.1).

Removing 250,000 tons does not have a feasible solution because it exceeds the maximum amount demanded by phosphorous-deficit counties. Setting the minimum amount of litter to be removed at 200,000 resulted in a removal cost of cost $19.70/ton, with 493 farms (53.4%) sending litter out of the watershed. More than 90.7% of this litter is from Delaware, Adair, Ottawa, Haskell and Cherokee counties. (Table V.2).

Doubling the minimum amount of litter to be transported out of the watershed increases slightly the amount taken from Ottawa, Muskogee and Sequoyah counties. It also increases substantially the amount taken from Adair, Delaware, and Haskell counties, while reducing the amount sent from Mayes and Pittsburgh counties.

Table V-1. Optimal Amount of Litter Transported from Oklahoma Poultry Farms to Fertilizer-Deficit Counties and Average Distance Transported: 100,000 tons Minimum

Source Counties	No Farms	Average Distance (miles)	Quantity (tons)	% of Total
ADAIR	10	158.16	3,240	3.24
CHEROKEE	27	186.22	10,080	10.08
CRAIG	9	98.89	3,840	3.84
DELWARE	94	181.30	37,960	37.96
HASKELL	38	185.51	13,200	13.2
MAYES	20	171.62	7,800	7.8
MCINTOSH	1	193.10	240	0.24
MUSKOGEE	6	170.67	1,440	1.44
OTTAWA	33	118.14	19,200	19.2
PITTSBURGH	2	232.91	960	0.96
SEQUOYAH	8	194.93	2,040	2.04
	248	170.10	100,000	
			1,570,000	
		Optimum transport cost ($/ton)	15.70	

Table V-2. Optimal Amount of Litter Transported from Oklahoma Poultry Farms to Fertilizer-Deficit Counties and Average Distance transported: 200,000 Tons Minimum

Source Counties	No Farms	Average Distance (miles)	Quantity (tons)	% of Total
ADAIR	88	212.30	46,920	23.46
CHEROKEE	27	208.57	10,080	5.04
CRAIG	1	57.89	480	0.24
DELAWARE	177	196.15	68,400	34.2
HASKELL	61	189.52	19,680	9.84
LATIMER	4	211.78	1,320	0.66
LEFLORE	56	229.57	19,520	9.76
MAYES	18	193.62	7,080	3.54
MCINTOSH	2	159.78	600	0.3
MUSKOGEE	7	187.23	1,560	0.78
OTTAWA	33	130.68	20,160	10.08
PITTSBURGH	2	177.41	720	0.36
SEQUOYAH	17	212.70	3,480	1.74
TOTAL	493	195.01	200,000	100
			3,943,229.9	
		Optimum transport cost ($/ton)	19.71	

Viewing the results from the perspective of the destination counties indicates that large amounts of surplus litter from the watershed could be delivered to most outside regions considered by this study. But the amount sent to Alfalfa county is much less than its demand because it is located relatively far from the source counties. As Table V.3 indicates, nothing is transported to Alfalfa County when only 100,000 tons are removed, and when 200,000 tons are removed, only 58% of its potential use is met.

Table V-3. Optimal Amount of Litter Transported from Oklahoma Poultry Farms vs. Amount Demanded by Oklahoma Fertilizer-Deficit Counties

	100,000 tons removed			**200,000 tons removed**	
Destination Counties	Demand (tons)	Quantity transported (tons)	%	Quantity transported (tons)	%
ALFALFA	90,000	0	0	52,070	57.86
CANDADIAN	16,500	16,500	100	16,500	100.00
GARFIELD	33,000	33,000	100	33,000	100.00
KINGFISHER	19,000	19,000	100	19,000	100.00
GRANT	62,000	62,000	100	62,000	100.00
OTTAWA	780	780	100	780	100.00
NOTAWA	5,700	5,700	100	5,700	100.00
ROGERS	900	900	100	900	100.00
OSAGE	8,000	8,000	100	8,000	100.00
WAGONER	750	750	100	750	100.00
WASHINGTON	1,300	1,300	100	1,300	100.00

When 100,000 tons are removed, poultry litter is shipped within an average hauling distance of 170 miles at an average cost of $15.70/ton. When 200,000 tons are removed the average hauling distance is extended to 195 miles and removal costs average $19.71/ton. The removal costs obtained by this model are less than the value of litter because it is assumed that farmers in fertilizer deficit counties would pay for the value of litter delivered to them. This result compares with results from Bosch and Napit for Georgia which showed that the highest cost of shipping surplus litter to deficit counties at an average hauling distance of 50 miles is $18.86/ ton. Parker's research in Maryland also agrees with this, finding that poultry litter could be shipped out with a unit cost of $21.00 per ton and $27.40/ton for distances of 90 and 150 miles, respectively. Paudel, Adhikari and Martin also estimated that litter can be economically transported up to a distance of 164 miles.

Govandasamy and Cochran noted that the value of the marginal product of litter as a fertilizer in a local pasture will increase as its opportunity cost of transporting outside the region declines. The result of this scenario shows that as the amount of litter to be removed increased from 100,000 to 200,000 tons, the shadow price (cost) of an additional ton of litter increased from $19.7 to $29.18. Therefore transporting litter out of the region may not be an attractive solution for a large quantity of litter.

Scenario II: Transporting or Processing Oklahoma Litter

In Scenario II, both processing the litter and transporting it outside the watershed are considered. Considering Oklahoma litter only, whether 100,000 tons or 250,000 tons must be removed from the watershed, the results recommend construction of a 300,000-ton capacity processing plant at site 22. Out of 924 poultry farms, 675 (73%) send their litter to this processing plant, attaining a profit (negative cost) of $734,261, or $2.28/ton. Poultry farms from Le Flore, Delaware, Adair, Haskell and Ottawa counties send more than 88.9% of the litter being processed in this plant (Table V.4). This plant produces 86.6 million kwh of electricity and 14,989 tons of fertilizer. The weighted average distance that litter is transported is 62 miles. No litter is transported out of the watershed in this Scenario. In this solution, the constraint for minimum amount of litter to be removed from the watershed is not binding. The level of utilization of the constructed plant is 88% of its capacity.

Table V-4. Optimal Amount of Oklahoma Poultry Litter Processed and Average Distance Transported: 100,000 tons and 250,000 tons Minimum

Source Counties	No. Farms	Average Distance (miles)	Amount (tons)	% of Total
ADAIR	79	18.41	43,560	16.48
CHEROKEE	27	31.07	10,080	3.81
CRAIG	7	66.12	3,840	1.45
DELAWARE	175	25.13	68,400	25.87
HASKELL	60	88.93	19,680	7.44
LATIMER	4	97.54	1,320	0.50
LE FLORE	246	92.4	83,280	31.50
MAYES	17	39.64	7,080	2.68
MCCURTAIN	3	180.26	600	0.23
MCINTOSH	2	87.48	600	0.23
MUSKOGEE	7	79.61	1,560	0.59
OTTAWA	31	62.42	20,160	7.63
PITTSBURG	2	107.17	720	0.27
PUSHMATAHA	0	188.94	0	0.00
SEQUOYAH	17	82.19	3,480	1.32
	660	62.28	264,360	100

In contrast, when 300,000 tons must be removed, the results recommend constructing a 400,000-ton capacity processing plant at site 1. In this situation, 798 farms (86%) are included within the market boundary. Poultry farms from Le Flore, Delaware, Adair, McCurtain, Haskell and Ottawa contribute more than 90.3% of the litter being processed. This processing plant produces 92M kwh of electricity and 17,010 tons of fertilizer at a profit (negative cost) of $632,110 or $2.10/ton. The weighted average distance that litter is transported is 78 miles (Table V.5). This plant will operate at 75% of its capacity.

Table V-5. Optimal Amount of Litter Processed and Average Distance Transported: 300,000 tons Minimum

Source Counties	No. Farms	Average Distance (miles)	Amount (tons)	% of Total
ADAIR	80	13.61	43,560	14.52
CHEROKEE	27	30.98	10,080	3.36
CRAIG	7	77.4	3,840	1.28
DELAWARE	175	37.27	68,400	22.8
HASKELL	60	81.33	19,680	6.56
LATIMER	4	89.93	1,320	0.44
LE FLORE	246	84.46	83,280	27.76
MAYES	17	49.86	7,080	2.36
MCCURTAIN	121	172.61	35,880	11.96
MCINTOSH	2	81.51	600	0.2
MUSKOGEE	7	72.07	1,560	0.52
OTTAWA	31	74.96	20,160	6.72
PITTSBURG	2	99.64	720	0.24
PUSHMATAHA	2	154.59	360	0.12
SEQUOYAH	17	47.7	3,480	1.16
	781	78.17	300,000	100

Scenario III: transporting or Processing Oklahoma and Arkansas Litter

When litter from both Oklahoma and Arkansas poultry farms is considered, whether 100,000 tons or 250,000 tons or 300,000 tons of litter must be removed from the watershed, the results recommend construction of a 400K-ton capacity processing plant at site 1 and a 500K-ton capacity plant at site 33. The two together process 810,000 tons of litter. No litter is transported outside the region. Both plants operate at the maximum 90% capacity utilization, and produce 265.36 Mkwh of electricity and 45,927 tons of fertilizer at a profit (negative cost) of $7,193,872 or $8.88/ton of litter. The litter processed at the 400K- ton plant is collected from 2,413 (29.34%) poultry houses from Arkansas and 168 (18.18%) poultry farms from Oklahoma, while the litter processed at the 500K-ton plant is collected from 2,841 (34.54%) houses from Arkansas and 252 (27.27%) from

Oklahoma farms. The amount of litter from Arkansas that is processed is 630,480 tons (78% of the total) and the amount processed from Oklahoma is 179,520 tons (22% of the total). The detail is presented in Table V.6.

In this solution, litter travels an average distance of 46 miles from Oklahoma poultry farms to the 400K-ton plant, and 31 miles from Arkansas houses to the same plant. For the 500K-ton plant, the average distance is 56 miles from Oklahoma farms and 45 miles from Arkansas poultry houses.

If the solution is restricted to only one plant, a 500K-ton capacity plant is constructed at site 22, processing 450,000 tons of litter. The litter is collected from 3,217 farms and houses; 80% is from Arkansas. This processing plant achieves a profit (negative cost) of $4,583,451, or $10.19/ton.

Table V-6. Optimal Amount of Litter Processed and Average Distance Transported: Oklahoma and Arkansas

Source Counties/ Houses	No. Farms	Average Distance (miles)	Amount in 400K-ton plant (tons)	% of total	Average Distance (miles)	No farms	Amount in 500K-ton plant (tons)	% total	Total for both plants	Both plant % of total
POULTRY HOUSES 1-2597	0	33.65	0	0.0	22.66	2,597	311,640	69.25	311,640	38.47
POULTRY HOUSES 2584-5303	2,413	30.94	289,560	80.4	45	244	29,280	6.51	318,840	39.36
POULTRY HOUSES 5305-8225	0	158.12	0	0.0	178.32	0	0	0.00		0.00
Sub total Arkansas	**2,413**	**30.94**	**289,560**	**80.4**	**45.00**	**2,841**	**340,920**	**75.76**	**630,480**	**77.84**
ADAIR	73	13.65	39,840	11.1	28.96	6	3,720	0.83	43,560	5.38
CHEROKEE	11	30.98	4,200	1.2	35.11	16	5,880	1.31	10,080	1.24
CRAIG	0	77.4	0	0.0	58.67	7	3,840	0.85	3,840	0.47
DELAWARE	0	37.27	0	0.0	17.27	175	68,400	15.20	68,400	8.44
HASKELL	7	81.33	2,160	0.6	99.59	0	0	0.00	2,160	0.27
LE FLORE	56	84.46	19,920	5.5	103.7	0	0	0.00	19,920	2.46
MAYES	0	49.84	0	0.0	35.46	17	7,080	1.57	7,080	0.87
MUSKOGEE	4	72.07	840	0.2	191.69	0	0	0.00	840	0.10
OTTAWA	0	74.96	0	0.0	53.33	31	20,160	4.48	20,160	2.49
SEQUOYAH	17	47.7	3,480	1.0	66.92	0	0	0.00	3,480	0.43
Sub total Oklahoma	**168**	**46.04**	**70,440**	**19.6**	**56.44**	**252**	**109,080**	**24.24**	**179,520**	**22.16**
TOTAL	2,581		360,000	100.0		3,093	450,000	100.00	810,000	100.00

When only Oklahoma litter is processed, 264,360 tons of litter are processed at a profit of $2.77/ton. Allowing litter from Arkansas to be processed in Oklahoma, two plants remove 810,000 tons of litter from the region, at a net profit of $8.88/ton. Savings in transportation cost and economies of size in processing account for this gain. From an Oklahoma perspective, however, a disadvantage of allowing Arkansas litter to be processed is that only 180,000 tons of Oklahoma litter (53%) is removed compared to 264,360 tons (78%) or 300,000 (88%) tons removed when only Oklahoma litter is allowed to be processed. (Figure V.1).

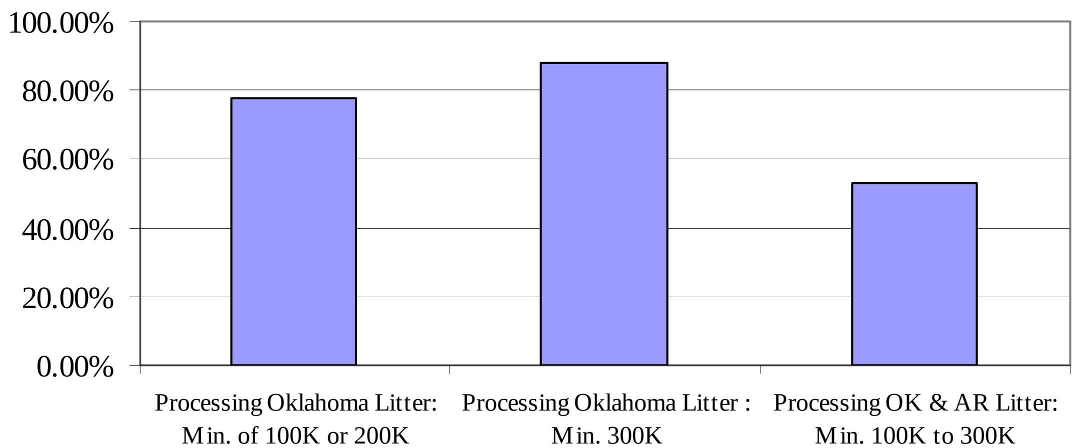

Figure V-1. Proportion of Oklahoma Litter Processed When Arkansas Litter Is Available

Processing or Transporting Litter from Oklahoma:

Reduced Processing Profitability

Scenario II is analyzed with an alternative assumption that expected processing profitability is reduced by 50%. Considering Oklahoma litter only, when a minimum of 100,000 tons must be removed from the watershed, the result suggests construction of a

100K-ton capacity processing plant at site 33 to process 90,000 tons of litter and transporting 10,000 tons of litter outside the watershed (to Ottawa, Nowata, Rogers, Wagoner, and Washington forage-producing counties). Out of 924 poultry farms, only 191(20.6%) send their litter to this processing plant and 24 (2.5%) send their litter to outside region with a net cost of $1,442,298 or $14.40/ton. Poultry farms from Delaware and Adair counties send more than 97% litter that is processed. This plant produces 29.48 M kwh of electricity and 5,103 tons of fertilizer. The weighted average distance litter is transported is 20.8 miles to the plant and 69.26 miles to counties outside the watershed. (Table V.7). The plant operates at 90% of its capacity and the transported litter meets 57.4% of the demand of forage-growing counties of Ottawa, Nowata, Rogers, Wagoner, and Washington.

When 250,000 tons of Oklahoma litter must be removed from the watershed, the results recommend construction of a 300K-ton capacity processing plant at site 22 (to process 248,740 tons of litter) and exporting 1,260 tons outside the watershed. Out of 924 poultry farms in Oklahoma, 640 (69.3%) send their litter to the processing plant and only 3 farms export their litter outside the watershed with a net cost of $1,442,298 or $12.31/ton. Poultry farms from Delaware, Adair, Le Flore, Haskell and Ottawa counties send more than 88.9% of the processed litter. This plant produces 81.5 M kwh of electricity and 14,104 tons of fertilizer. The weighted average distance that litter is transported is 57 miles to the plant and 186 miles to fertilizer-deficit counties outside the watershed (Table V.8). The plant operates at 83% of its capacity and meets 7.2% of the demand of forage-growing counties outside the watershed.

When 300,000 tons of Oklahoma litter must be removed from the watershed, the results indicate construction of a 400K-ton capacity processing plant at site 1 (to process 299,220 tons of litter) and transporting only 1,260 tons outside the watershed. Eight hundred and four poultry farms (87%) send their litter to this plant while only 4 farms send their litter to outside region with a net cost of $3,883,807 or $12.9/ ton. Poultry farms from Delaware, Latimer, Adair, McCurtain, Adair and Muskogee counties send more than 83.7% of the processed litter. This plant produces 98 M kwh of electricity and 16,939 tons of fertilizer. The weighted average distance that litter is transported is 76 miles to the plant and 111.5 miles to counties outside the watershed. (Table V.7). With this situation the plant operates at 75% of its capacity and satisfies only 7.2% of the demand of fertilizer deficit farms.

Table V-7. Optimal Amount of Oklahoma Litter Processed or Transported Outside the Watershed and Average Distance Transported with Assumption of Reduced Processing Profitability: 100,000 tons Minimum

Poultry Litter Source Counties	Farms	Average distance (miles)	Amount Processed or transported (tons)	% of total
ADAIR	40	28.96	30,960	34.40
CHEROKEE	5	35.11	2,160	2.40
DELAWARE	145	17.27	56,400	62.67
MAYES	1	35.46	480	0.53
Total Processed	**191**	**20.28**	**90,000**	**100.00**
ADAIR	2		750	7.5
CHEROKEE	10		4,080	40.8
MAYES	4		1,680	16.8
OTTAWA	8		3,490	34.9
***Total Transported**	**24**	**69.26**	**10,000**	**100.00**

*Destination counties are the forage-producing counties of Ottawa, Nowata, Rogers, Wagoner, and Washington.

Table V-8. Optimal Amount of Oklahoma Litter Processed or Transported outside the Watershed and Average Distance Transported with Assumption of Reduced Processing Profitability: 250,000 tons Minimum

Poultry Litter Source Counties	Farms	Average distance (miles)	Amount Processed or transported (tons)	% of total
ADAIR	79	18.41	43560	17.51
CHEROKEE	27	31.07	10,080	4.05
CRAIG	6	66.12	3,360	1.35
DELWARE	182	25.13	68,400	27.50
HASKELL	60	88.93	19,680	7.91
LATIMER	4	97.56	1,320	0.53
LE FLORE	210	92.4	70,240	28.24
MAYES	17	39.64	7,080	2.85
MCINTOSH	2	87.48	600	0.24
MUSKOGEE	7	79.61	1,560	0.63
OTTAWA	29	62.42	19,380	7.79
SEQUOYAH	17	55.56	3,480	1.40
Total Processed	**640**	**57.12**	**248,740**	**100.00**
CRAIG	1		480	38.10
OTTAWA	2		780	61.90
***Total Transported**		**186**	**1,260**	**100.00**

* Destination counties are the forage-producing counties of Ottawa and Nowata

Table V-9. Optimal Amount of Oklahoma Litter Processed or Transported outside the Watershed and Average Distance Transported with Assumption of Reduced Processing Profitability: 300,000 tons Minimum

Poultry Litter Source Counties	Farms	Average distance (miles)	Amount processed or transported (tons)	% of total
ADAIR	79	13.65	43,560	14.56
CHEROKEE	27	30.98	10,080	3.37
CRAIG	6	77.4	3,360	1.12
DELWARE	182	37.27	68,400	22.86
HASKELL	60	81.33	19,680	6.58
LATIMER	4	89.93	1,320	0.44
LEFLORE	246	84.46	83,280	27.83
MAYES	17	49.84	7,080	2.37
MCCURTAIN	121	172.61	35,880	11.99
MCINTOSH	2	81.51	600	0.20
MUSKUGEE	7	72.07	1,560	0.52
OTTAWA	29	74.96	19,380	6.48
PITTUSBURG	2	99.64	720	0.24
PUSHMATAHA	2	154.48	360	0.12
SEQUOYAH	20	47.7	3,960	1.32
Total Processed	**804**	**76.14**	**299,220**	**100.00**
CHEROKEE	1		480	38.10
MUSKOGEE	3		780	61.90
***Total Transported**	**4**	**111.48**	**1,260**	**100.00**

* Destination counties are the forage-producing counties of Ottawa and Nowata

To summarize, the result of Scenario II indicates that when processing is not as profitable as expected, the optimum solution includes processing as well as transporting of litter outside the region. When 100,000 tons or 250,000 tons of litter must be removed from the watershed a 300K-ton capacity processing plant which attains a profit of $2.78/ ton is constructed. When the amount of litter that must be removed is raised to 300,000 tons a 400K-ton capacity processing plant which makes a profit of $2.11/ ton is constructed. Thus, with an increase in the minimum level of litter to be removed from the region, the plant size increases but capacity utilization decreases from 88% to 75%. This decrease in capacity utilization limits the ability of the 400K-ton plant to achieve economies of size, and reduces its profitability.

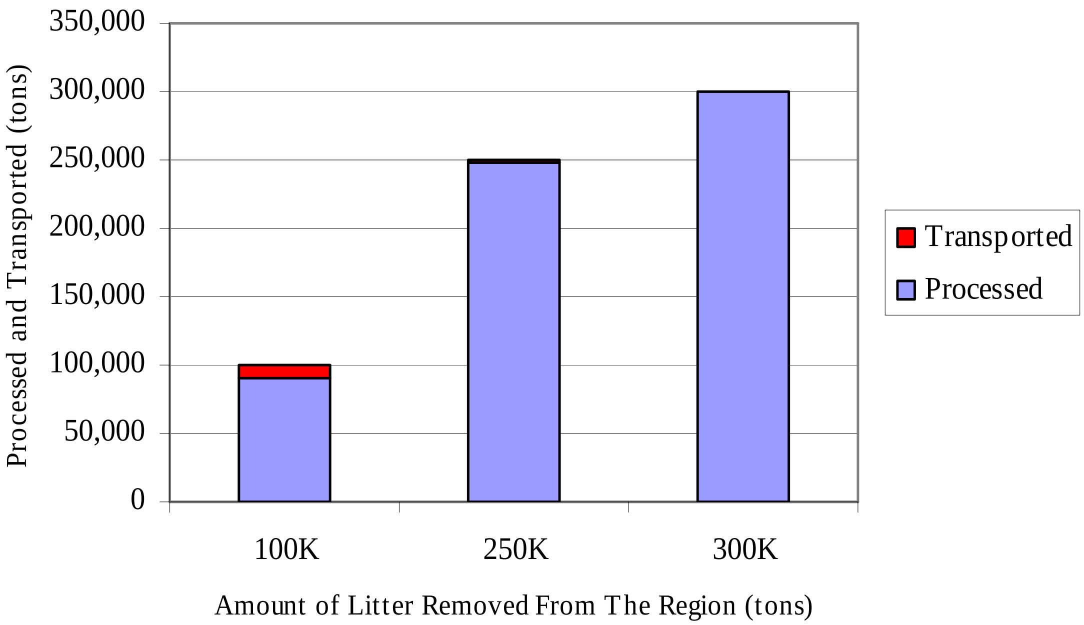

Figure V-2. Amount of Litter Processed and Transported Under Reduced Processing Profitability

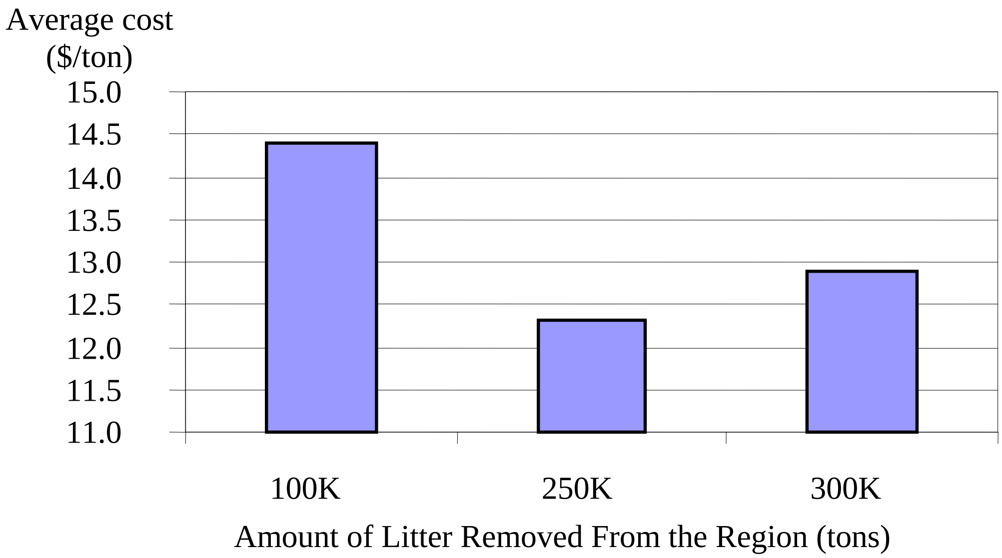

Figure V-3. Cost Trend with Increased Amount of Litter Removed from the Region Under Reduced Processing Profitability

Processing or Transporting Litter from Oklahoma and Arkansas:

Reduced Processing Profitability

When both Oklahoma and Arkansas litter may be processed, but processing profitability is 50% of the expected profit and the model is constrained to process or transport out of the watershed a minimum of 100K tons of litter, the optimization model recommends constructing a 100K-ton plant at site 1.

Operating at 90% capacity, the plant processes 90K tons, and 10K tons are transported out of the watershed to forage farms in Ottawa, Nowata, Rogers, Wagoner, and Washington counties. Five-hundred-eighty-one poultry farms send litter to the processing plant, while 24 farms send it outside the region. Of the processed litter, more than 72% is from Arkansas. The remaining 28% of the litter that is processed, and all 10,000 tons sent outside the region, is from Oklahoma.

The plant would produce 29 M kwh of electricity and 5,103 tons of fertilizer. This combination of processing and transporting 100K tons of litter would cost $1,345,954, or $13.50/ton. The weighted average distance transported is 21.5 miles for litter that is processed, and is 49.5 miles for litter that is transported out of the region (Table V.10).

When the model is constrained to process or transport at least 250K tons, the model recommends construction of a 300K-ton plant at site 33. The plant processes 250K tons, and no litter is transported out of the region. More than 75% of the processed litter is from Arkansas, and less than 25% is from Oklahoma. The plant produces 81.9 M kwh of electricity and 14,175 tons of fertilizer at a cost of $1,949,055, or $7.79/ton. The weighted average distance litter is transported is 24 miles (Table V.11).

Table V-10. Optimal Amount of Litter Processed or Transported and Average Distance Transported: Minimum 100,000 tons

Poultry Litter Source Counties	No. farms	Average distance (miles)	Processed or Transported (tons)	% of total
POULTRY HOUSE 2732-4389	511	22.16	64,920	72.13
ADAIR	40	13.65	25,080	27.87
Total Litter processed	**551**	**21.54**	**90,000**	**100.00**
CHEROKEE	2		750	7.5
CRAIG	8		3,840	38.4
DELAWARE	1		240	2.4
MAYES	4		1,680	16.8
OTTAWA	9		3,490	34.9
***Total Litter transported**	**24**	**49.5**	**10,000**	**100.0**

* Destination counties are the forage-producing counties of Ottawa, Nowata, Rogers, Wagoner, and Washington counties

When the model is constrained to process or transport at least 300K tons, the model recommends construction of a 400K-ton plant at site 22. The plant process 360K-tons. and no litter is transported out of the region. More than 79% of the processed litter is from Arkansas while less than 21% is from Oklahoma. The plant produces 117.93 M kwh of electricity and 20,412 tons of fertilizer at a cost of $1,952,039 or $5.40/ton. The weighted average distance litter is transported is 26 miles (Table 5.12).

Table V-11. Optimal Amount of Litter Processed or Transported and Average Distance Shipped : Minimum 250,000 tons

Source Counties/ Houses	No. farms	Average distance (miles)	Processed (tons)	% of total
POULTRY HOUSES 125-3433	1,570	24.44	188,400	75.36
Sub total Arkansas	1,570		188,400	75.36
ADAIR	19	28.96	18,280	7.31
CHEROKEE	1	35.11	240	0.09
DELAWARE	116	17.27	43,080	17.23
Sub total Oklahoma	136		61,600	24.63
TOTAL	1,706	24.01	250,000	100.00

Table V-12. Optimal Amount of Litter Processed or Transported and Average Distance Transported: Minimum 300,000 tons

Poultry Litter Source Counties	No. farms	Average distance (miles)	Processed (tons)	% of total
POULTRY HOUSE 125-4615	2,379	26.47	285,480	79.30
Sub total Arkansas	2,379		285,480	79.30
ADAIR	55	18.41	36,240	10.07
CHEROKEE	5	31.07	2,160	0.60
DELAWARE	96	25.13	36,120	10.03
Sub total Oklahoma	96		74,520	20.70
TOTAL	2,535	26.25	360,000	100.00

Under the assumption of reduced profitability, the constraint on minimum amount of litter to be processed or transported out of the watershed is binding; raising this constraint raises the amount of litter that is removed from the watershed. But under the original assumption of full processing profit and the assumption that both Oklahoma and Arkansas litter can be processed, none of the simulations indicated that transporting litter out of the region was optimal (Figure V.4.). Ironically, though, under reduced profitability, raising the constraint also reduces the average cost of removing the litter. The smaller the constraint, the less litter will be removed from the region, either through processing or transporting it outside the region. However, raising the minimum amount to be removed allows economies of size to reduce the cost of removing the litter. This figure also shows that when processing is profitable, as originally assumed, the constraint has no effect both on the quantity of litter to be removed and on average cost of removal. (Figure 5.4 and 5.5).

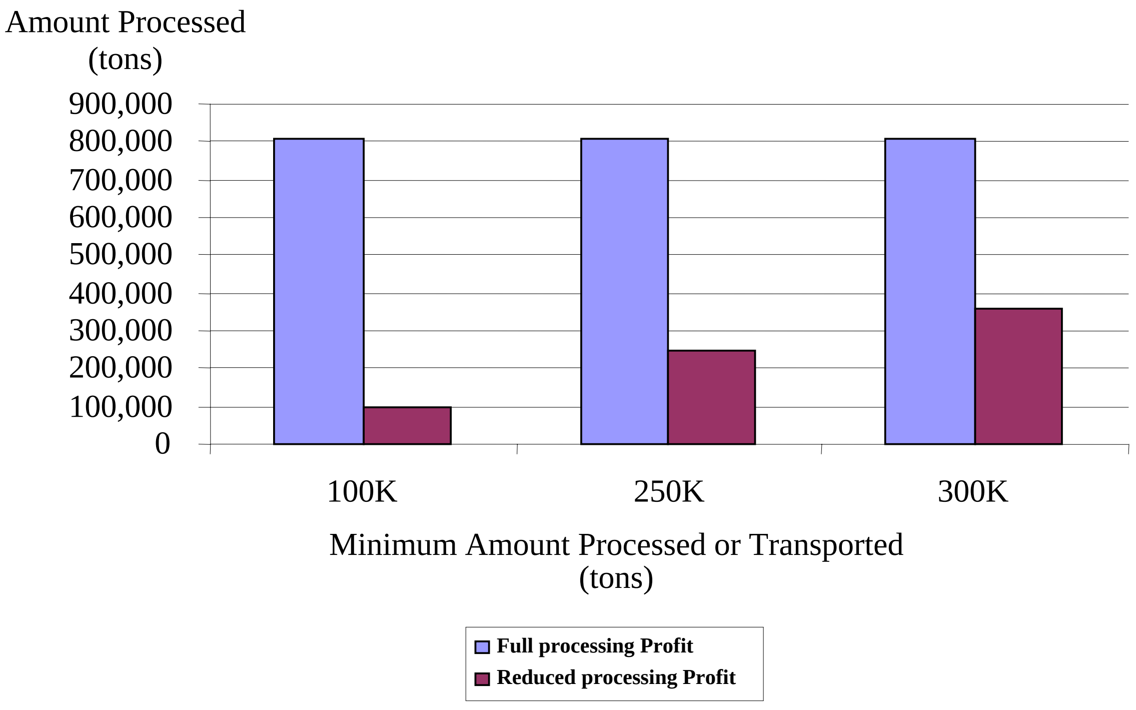

Figure V-4. Amount of Oklahoma and Arkansas Poultry Litter Processed for Alternative Minimum Amounts of Litter Removed from the Watershed

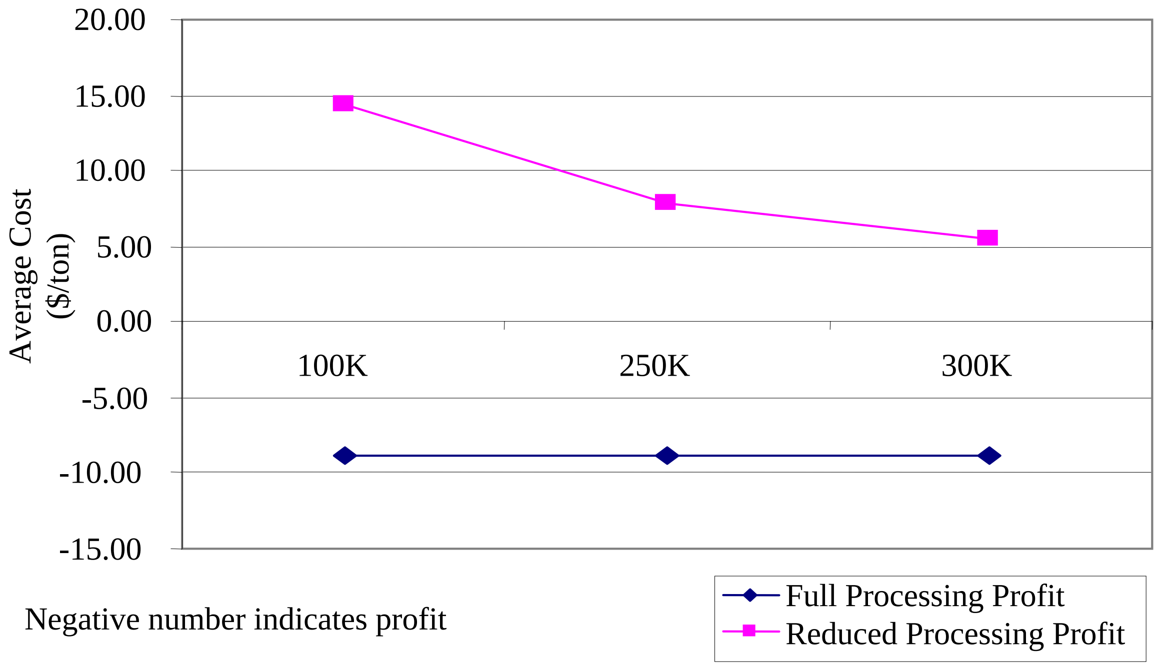

Figure V-5. Average Processing Cost for Oklahoma and Arkansas Poultry Litter for Alternative Minimum Amounts of Litter Removed from the Watershed

Figure V.6 shows, as Figure V.1 did for the full profitability assumption, that allowing Arkansas litter to be processed with Oklahoma plants reduces the amount of Oklahoma litter that will be removed from the region either by processing or by transporting it outside the region. From a regional water quality perspective, if litter from Arkansas and Oklahoma farms affects the water in similar ways, which of the states is the source of litter does not matter. However, if a goal is to reduce the amount of litter applied to Oklahoma land, allowing Arkansas farms to send litter to be processed limits the ability to achieve this goal.

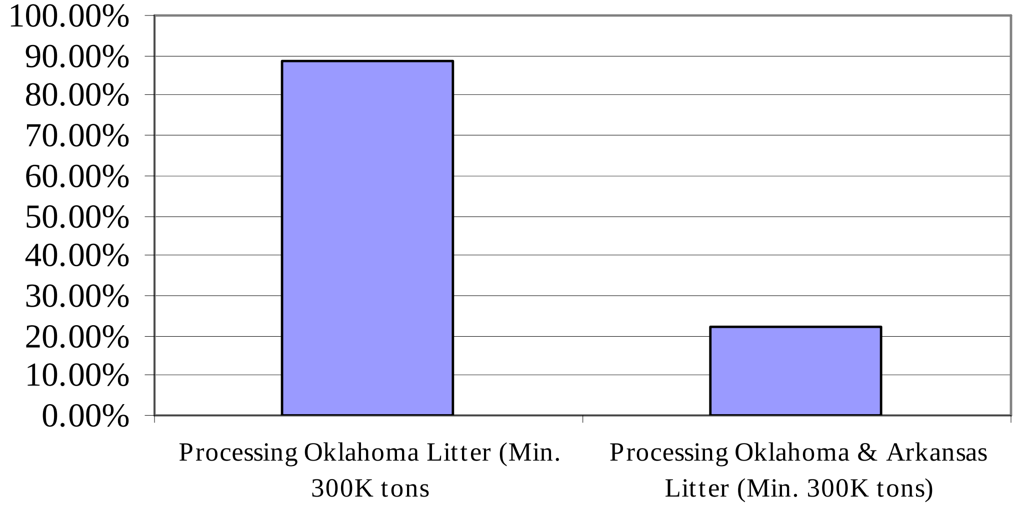

Figure V-6. Proportion of Oklahoma Litter Processed: Processing only Oklahoma Litter vs. Processing Oklahoma and Arkansas Litter

CHAPTER VI

SUMMARY, CONCLUSION AND RECOMMENDATIONS

The purpose of this study was to minimize the cost of removing specified amounts of litter from a watershed by processing it, by transporting it from the watershed to phosphorous-deficit areas, or both. The study was conducted in three different scenarios. Scenario I analyzed the reduction of poultry litter of Oklahoma with an assumption that no processing plant is established. In this situation, continuous variables represented the quantity of litter transported from each poultry growers to each selected wheat-and/or forage-growing county outside the watershed. A linear programming model was used to determine the optimum solution.

Scenario II examined the combined alternatives of establishing processing plants and transporting some amount of Oklahoma poultry litter outside the watershed. In this case, binary variables were used to select or not select a particular location and processing plant capacity. Mixed integer programming was used to find the optimum solution. Scenario III was like Scenario II, but included poultry litter from western Arkansas.

Since the assumptions about profitability of processing plants were projections and have not been tested, the model results were tested for sensitivity to an alternative assumption. The alternative assumption was that, rather than achieving its expected profitability, the processing plant achieved only half that amount. This might happen, for example, if electricity or fertilizer yields were lower than predicted, or if wholesale electricity and fertilizer prices were lower than predicted, or if the “green energy” tax credit (currently 1.8¢/kwh) were not available.

The model choice variables were quantities of litter transported from each farm to each processing plant and processed, capacity of each processing plant that is built, and quantity of litter transported from each farm to each of several phosphorous-deficit counties.

The model selected one of five plant capacities for each five prospective plant locations: 100,000, 200,000, 300,000, 400,000 and 500,000 tons per year of litter processing capacity. Alternatively, the model chose to build no plant at a particular location. Binary variables were used to model these choices. Continuous variables were used to determine the quantity of litter transported from each farm.

Key Results:

- Using previous projections of processing profitability, the model’s optimum solution is to build one 400,000-ton capacity plant and one 500,000-ton capacity plant. Operating at 90% capacity, the 400K-ton plant processes 289,560 tons of Arkansas litter and 70,440 tons of Oklahoma litter, while the 500K-ton plant processes 340,920 tons of Arkansas litter and 109,080 tons of Oklahoma litter. Profit achieved is $8.88/ton of litter.
- If processing is as profitable as projections indicate, processing is an effective way of removing litter from the region, and no mandates are necessary. Transporting litter out of the region is more costly.

- If processing is 50% less profitable than projections indicate, it is still less costly than transporting the litter out of the region, and thus an effective way of removing the litter from the region. However, neither processing nor transporting litter out of the region will occur without incentives or mandates, such as a constraint on minimum amount of litter to be removed. In this case, raising the minimum amount of litter that must be removed reduces per-ton cost of removing litter because it forces larger amounts to be processed, taking advantage of economies of size in processing.
- There is a tradeoff between reducing cost (increasing profitability) of removing litter, and amount of litter removed from Oklahoma. Profitability is increased by allowing Arkansas litter to be processed, but this reduces the amount of litter to be removed from Oklahoma.

Limitations and Suggestions for Future Research

First, this study did not consider opportunities for reallocating litter within the watershed, as work by Ancev did. Future research should consider combining this research with opportunities for moving litter from phosphorous-surplus areas to phosphorus-deficit areas within the watershed.

Second, this study assumed that all poultry farms would willingly send their litter to a processing plant or to destinations outside the watershed, if the model's solution indicated that. Further, ownership structure of the plant and its effect on operational efficiency and grower incentives has not been considered. Future research should allow for lower participation rates by poultry growers, or consider producer participation decisions in a profit-maximizing framework, together with institutional factors.

Third, this study has not examined the full effects of political and institutional constraints on the optimum solution. For example, this study assumed that because much of the governmental support for processing litter in the watershed came from the state of Oklahoma, any plant built would be located in Oklahoma, even if purely economic considerations might indicate that a plant should be built in Arkansas. There may be similar political and perhaps institutional constraints that limit the relative amounts of Oklahoma and Arkansas litter that can be processed in a plant located in Oklahoma.

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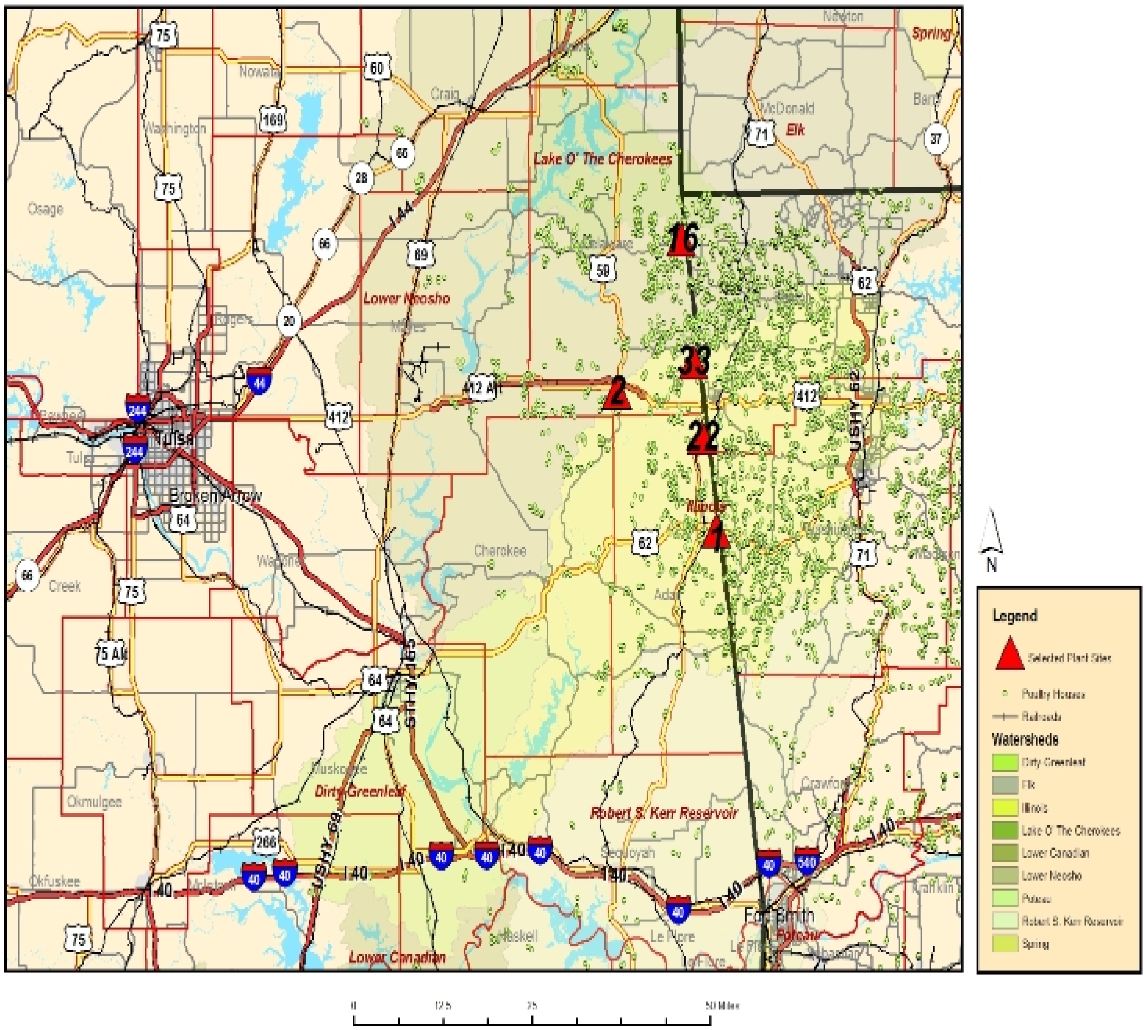
APPENDIX A

SELECTED DEMONSTRATION SITES OF ALTERNATIVE PLANTS

Selected Demonstration Plant Sites



Source: Allen Finchum

APPENDIX B

LINEAR PROGRAMMING MODEL FOR TRANSPORTING

POULTRY LITTER OUTSIDE THE WATERHSED

Scenario I Model

```
$OFFUPPER OFFSYMXREF OFFSYMLIST OFFUELLIST OFFUELXREF
OPTION limrow=0, limcol=0;
OPTION optcr = 0.0000;
*OPTION solprint=off;
OPTION OPTCR=0
OPTION reslim=500000;
OPTION iterlim=500000;

SET
I  Poultry Litter Source
/F8226*F9149/

E Desitnation outside regions

/Alfalfa,Canadian,Garfield,Kingfisher,Grant,Ottawa,Nowata,Rogers,Osage,Wagoner,
Washington/

SCALAR M   Maximum amount of litter produced in Oklahoma & Arkansas
watershed/2000000/;
SCALAR L   MINIMUM amount of litter to be taken out of the watershed/200000/;


PARAMETER S(I) Poultry litter production in each farms(tons)

       (Large data size so made available only electronically)

PARAMETER V(E) Unit price of litter per ton at E($)
  /Alfalfa    8.58
 Canadian     8.58
 Garfield     8.58
 Kingfisher   8.58
 Grant        8.58
 Ottawa       9.88
 Nowata       8.78
 Rogers       9.69
 Osage        7.47
 Wagoner      9.88
 Washington   7.28/;

PARAMETER B(E) Poultry litter demand at E(in ton)
/Alfalfa      90000
 Canadian     16500
 Garfield     33000
 Kingfisher   19000
 Grant        62000
 Ottawa         780
 Nowata        5700
 Rogers         900
 Osage         8000
 Wagoner        750
 Washington    1300 /;

VARIABLES

XO(I,E)   Quantity of poultry litter transported from source i to outside
region E
 Z        Total transportation COST;

POSITIVE VARIABLES XO;
```

```
EQUATIONS
         COST            Objective function COST MINIMIZATION

         DEMAND(E)    Satisfy litter demand at plant J of capacity p and at
external region E
         SUPPLY(I)      Satisfy litter supply at I for plants
         MAXLIT          Maximum litter amount in the region
         MINLIT          Minimum amount of litter to be taken out from the
region;


         COST..  Z =E= SUM((I,E),K(I,E)*XO(I,E))-SUM((I,E),V(E)*XO(I,E));


         DEMAND(E)..  SUM(I, XO(I,E)) - B(E) =L= 0;
         SUPPLY(I)..   SUM(E, XO(I,E))- S(I) =L= 0;

         MAXLIT..   SUM((I,E),XO(I,E)) - M =L= 0;
         MINLIT..   SUM((I,E),XO(I,E)) - L =G= 0;


MODEL POULTRYLITAL /ALL/;

SOLVE POULTRYLITAL MINIMIZING Z USING LP;

DISPLAY XO.L;
```

APPENDIX C

MIXED INTEGER PROGRAMMING MODEL FOR

PROCESSING POULTRY LITTER INTO SALABLE

FERILIZER AND ELECTRICITY AND

TRANSPORTING SOME AMOUNT

OUTSIDE THE WATERSHED

Scenario II and III Model

```
$OFFUPPER OFFSYMXREF OFFSYMLIST OFFUELLIST OFFUELXREF
OPTION limrow=0, limcol=0;
OPTION optcr = 0.0000;
*OPTION solprint=off;
OPTION OPTCR=0
OPTION reslim=500000;
OPTION iterlim=500000;

SET
I  Poultry Litter Source
/F8226*F9149/

J Destination plants location
 /site1,site2,site16,site22,site33/

E Desitnation outside regions

/Alfalfa,Canadian,Garfield,Kingfisher,Grant,Ottawa,Nowata,Rogers,Osage,Wagoner,
Washington/


P Plant size
    /P1,P2,P3,P4,P5/


T  Fertilizer type
     /N, Ph, K/


SCALAR PROP Proportion of processing capcity/0.9/;
SCALAR CNVG KWH of electricity in one ton of poultry litter /327.61/;
SCALAR RG Unit price per kwh of electricity /0.04/;
SCALAR L   MINIMUM amount of litter to be taken out of the watershed/100000/;

PARAMETER S(I) Poultry litter production in each farms(tons)

             (Large data size so made available only electronically)

TABLE C(I,J) cost of transporting litter from poultry house I to plant location
J

             (Large data side so made available only electronically)

TABLE K(I,E) cost of transporting litter from poultry house I to outside region
E

             (Large data size so made available only electronically)

TABLE PC(P,P) processing cost of different plant capacities
           P1    P2    P3      P4      P5
  P1     10.50
  P2           8.87
  P3                 8.28
  P4                        7.10
  P5                                6.94;

TABLE CNV(T,T) Conversion of fertilizer(pound of fertilizer per ton of litter)
              N        Ph      K
         N  37.8
         Ph          37.8
         K                   37.8;
```

```
TABLE R(T,T)  Fertilizer price(unit price per pound of fertilizer)

              N        Ph       K
         N  0.18
         Ph          0.09
         K                   0.18;

PARAMETER B(E) Poultry litter demand at E(in ton)
/Alfalfa      90000
 Canadian     16500
 Garfield     33000
 Kingfisher   19000
 Grant        62000
 Ottawa         780
 Nowata        5700
 Rogers         900
 Osage         8000
 Wagoner        750
 Washington    1300 /;

TABLE PCAP(J,P) Annual litter utilization capacity per plant (tons)
               P1      P2      P3      P4      P5
 site1      100000  200000  300000  400000  500000
 site2      100000  200000  300000  400000  500000
 site16     100000  200000  300000  400000  500000
 site22     100000  200000  300000  400000  500000
 site33     100000  200000  300000  400000  500000;

TABLE FCAP(J,P) Annual fertilizer processing capacity per plant(lbs)

            P1            P2         P3         P4          P5
 site1    11340000   22680000  34020000   45360000   56700000
 site2    11340000   22680000  34020000   45360000   56700000
 site16   11340000   22680000  34020000   45360000   56700000
 site22   11340000   22680000  34020000   45360000   56700000
 site33   11340000   22680000  34020000   45360000   56700000;

TABLE GCAP(J,P) Annual electricity production capacity per plant(KWH)
                   P1          P2           P3           P4            P5
 site1       32761000    65522000    98283000     131044000    163805000
 site2       32761000    65522000    98283000     131044000    163805000
 site16      32761000    65522000    98283000     131044000    163805000
 site22      32761000    65522000    98283000     131044000    163805000
 site33      32761000    65522000    98283000     131044000    163805000;


 TABLE FC(J,P) Annual intital investment & fixed cost of the processing plant J
             P1         P2           P3           P4             P5
 site1     1159300    1654000      2054400   2403900       2719600
 site2     1159300    1654000      2054400   2403900       2719600
 site16    1159300    1654000      2054400   2403900       2719600
 site22    1159300    1654000      2054400   2403900       2719600
 site33    1159300    1654000      2054400   2403900       2719600;


VARIABLES
XP(I,J,P) Quantity of poultry litter transported from source i to plant
locations J of plant size P
XO(I,E)   Quantity of poultry litter transported from source i to outside
region E
F         Quantity of fertilizer produced at J plant size p
G         Quantity of electricity produced at J plant size p
```

```
Z         'Total transportation, processing and annual fixed costs'
Y(J,P)    Zero one variable for plant size P at J;


POSITIVE VARIABLES XP, XO, F,G;
BINARY VARIABLE Y;

EQUATIONS
         COST           Objective function COST MINIMIZATION
         ELECTRICTY     Electricty produced in plant size P at location J
         FERTILIZER     Fertilizer produced in plnat size P at location J
         FPROC(J,P,T)    Fertilizer processing capacity in plant size p at J
         GPROC(J,P)      Electricity processing capacity in plant size p at J
         CAPACITY (J,P)  Satisfy litter demand at plant J of capacity p
         DMAND (E)    Satisfy litter demand at external region
         SUPPLY(I)     Supply limit at source i
          MINLIT          Minimum amount of litter to be taken out from   the
       region
         LOCPL(P)       At most one location J per plant size P
         PLTLOC(J)       At most one plant size P per location J;

         COST..  Z =E= SUM((I,J,P), C(I,J)*XP(I,J,P))+
SUM((I,E),K(I,E)*XO(I,E))+ SUM((I,J,P), PC(P,P)*XP(I,J,P))
                         + SUM((J,P), FC(J,P)*Y(J,P)) -
SUM((I,J,P,T),XP(I,J,P)*CNV(T,T)*R(T,T)) - SUM((I,J,P),XP(I,J,P)*CNVG*RG);

         ELECTRICTY.. G =E= SUM((I,J,P), XP(I,J,P)*CNVG);
         FERTILIZER.. F =E= SUM((I,J,P,T), XP(I,J,P)*CNV(T,T));
         CAPACITY (J,P)..  SUM(I, XP(I,J,P)) - PROP*PCAP(J,P)*Y(J,P) =L= 0;
         DMAND (E)..    SUM(I, XO(I,E))-B(E) =L= 0;
         SUPPLY(I)..   ( SUM((J,P), XP(I,J,P)) + SUM(E, XO(I,E))) - S(I) =L= 0;
         FPROC(J,P,T).. SUM(I, XP(I,J,P)*CNV(T,T)) - PROP*FCAP(J,P)*Y(J,P) =L=
0;
         GPROC(J,P).. SUM(I, XP(I,J,P)*CNVG) - PROP*GCAP(J,P)*Y(J,P) =L= 0;
         MINLIT..   SUM((I,J,P), XP(I,J,P)) + SUM((I,E),XO(I,E)) - L =G= 0;
         PLTLOC(J)..  SUM(P, Y(J,P)) =L= 1;
         LOCPL(P)..   SUM(J, Y(J,P)) =L= 1;
         Y.L(J,P) = 1;

MODEL POULTRYLITAL /ALL/;

SOLVE POULTRYLITAL MINIMIZING Z USING MIP;

DISPLAY XP.L, XO.L, F.L, G.L, PLTLOC.L, Y.L;
```

VITA

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Masters of Science

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