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Animal Manure as Alternatives to Commercial Fertilizers in the Southern High Plains of the United States: How Oklahoma Can Manage Animal Waste

J.D. Vitale, C. Penn, S. Park, J. Payne, J. Hattey and J. Warren
Oklahoma State University
U.S.A.

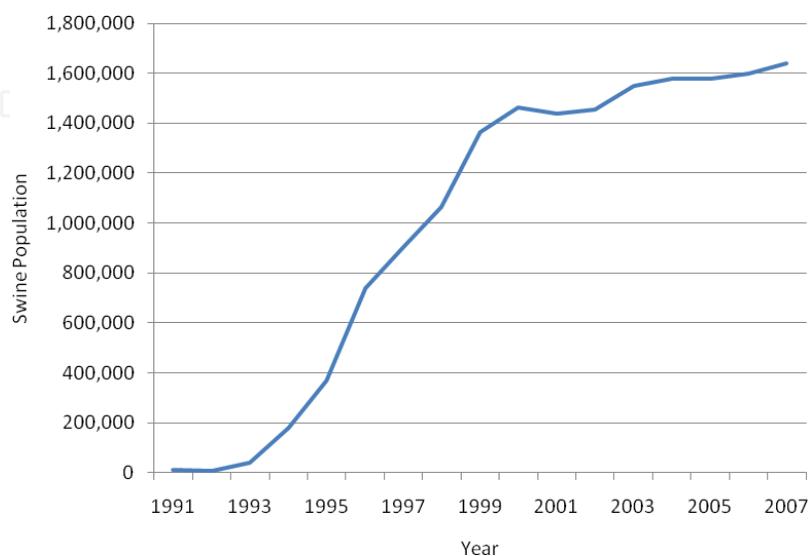
1. Introduction

The Southern High Plains (SHP) in the United States is one of the leading livestock producing regions in the US (Wright et al., 2010). More than 7 million fed cattle, which accounts for about 30% of the nation's production, are currently marketed annually in this region (Biermacher et al., 2005). Most recognize the Oklahoma Panhandle as the epicenter of the 1930's Dust Bowl in the U.S., but over the past two decades swine production in the Oklahoma Panhandle has increased 164 fold as illustrated in Figure 1 (Lowitt, 2006). Today the Panhandle is one of the more important swine producing regions in the U.S (Park et al., 2010). As elsewhere in the U.S., e.g. Iowa and North Carolina, the exponential rise in swine numbers was from the intensification of swine production, i.e. including concentrated animal feeding operations (CAFOs) and other large scale feeding operations (Williams, 2006). The Oklahoma Senate Bill 518 was passed in 1991, which eased restrictions on large concentrated animal feeding operations (Carreira et al., 2006).

A similar story has taken place in Eastern Oklahoma, which experienced a similar exponential growth of poultry production in the 1990's (Fochta, 2002). Approximately 48.2 million birds were produced in Oklahoma during 2007 (NASS, 2007). Over the past two decades, the continuous application of poultry litter, a mixture of bedding material and manure, on some poultry farm's soils has led to a build-up of phosphorus (M3-P), at times exceeding 150 and 200 mg kg⁻¹ (Penn et al., 2011). Because of current environmental regulations that prevent further P application once thresholds are met, there now exists a need to move the poultry litter off-farm (Van Horn, et al., 1996; Collins and Basden, 2006).

The large-scale animal feeding operations in beef cattle, swine, and poultry production have played a major role in the economy of the southern high plains region (Carreira et al., 2007). The introduction of the animal production industries has provided a more profitable alternative to traditional agricultural enterprises in the region, such as wheat and stocker cattle, which have struggled to remain competitive with producers in the more profitable Corn Belt. For instance, the swine industry's economic importance in the Oklahoma

Panhandle includes generating more than \$600 million in revenues and the creation of about 16 thousand jobs within the region. Likewise, the poultry industry in Eastern Oklahoma has generated 11,000 jobs over the past two decades and in an average year accounts for an added \$700 million in revenue to the local economy.



Source: NASS (2008).

Fig. 1. Swine population numbers in Oklahoma: 1991-2007.

The growth of the swine and livestock industries in the southern high plains region has led to unintended consequences, i.e. palpable discontent and apprehension over the management of animal waste by local citizenry and environmental groups (Fochta, 2002). Environmental concerns associated with the improper management of animal waste include surface and subsurface water quality degradation (eutrophication and nitrogen leaching) and air emissions (Williams, 2006). As early as 1998, before the swine and livestock industries had yet to reach their peak numbers, citizen groups had already lobbied state government to limit further expansion of CAFOs in the Oklahoma Panhandle (Hinton, 1998). In Eastern Oklahoma, even greater opposition has surfaced as waterways have become impaired, affecting drinking water and recreational uses (DeLaune et al., 2006). The public outcry led to a series of public laws that placed stricter guidelines on the handling and use of animal wastes. The link between mismanagement of animal waste and increased phosphorus reaching waterways has led to regulations regarding the land application of animal wastes such as poultry litter (Britton and Bullard, 1998).

In the past, animal waste has been managed by applying it as fertilizer at rates that satisfy crop nitrogen recommendations, which has provided operators in areas of intensive livestock and poultry production with a means to utilize animal waste in a beneficial manner (Reddy et al., 2008; Eghball and Power, 1999). Because the nutrient ratio in litter is different from plant nutrient ratio requirements, careful consideration must be taken when land applying animal waste to avoid over-application of certain nutrients (Penn et al., 2011).

In Oklahoma, phosphorus is likely to be over-applied if animal waste is applied on the basis of satisfying nitrogen levels. Continuous application of poultry litter to plants at N

recommended rates has been shown to cause an increase in soil test phosphorus (STP) beyond agronomic optimum (Sistani et al., 2004; Maguire et al., 2008). For Oklahoma, this agronomic optimum is 32.5 mg kg⁻¹ Mehlich-3 P (M3-P). One consequence of increased STP is a greater potential for non-point transport of phosphorus to surface water bodies through overland flow (Johnson et al., 2004; Daniel et al., 1994). Input of phosphorus into surface waters can cause eutrophication (Williams et al., 1999; Boesch et al., 2001). Eutrophication is characterized by excess plant growth and oxygen depletion in water and can result in algal blooms, taste and odor problems, and fish kills. This not only reduces attractiveness for recreation, but creates water quality concerns for drinking water supplies. Moreover, the effects of over-application can take a few years to cause a problem.

The link between STP and increased potential transport of phosphorus to surface waters has led to regulations regarding the land application of animal wastes such as poultry litter. For example, in Oklahoma, soils within "nutrient limited watersheds" (such as the Illinois River Basin) possessing M3-P values greater than 150 mg kg⁻¹ are not permitted to receive phosphorus applications. For non nutrient limited watersheds, soils with greater than 200 mg kg⁻¹ M3-P are only permitted to receive a maximum phosphorus application equal to plant phosphorus removal rates (NRCS, 2007). Much of the Oklahoma poultry production is located in the eastern portion of the state where nutrient limited watersheds are abundant (Britton and Bullard, 1998).

Marketing poultry litter outside of impacted watersheds to nutrient-deficient areas offers one solution to the litter surplus problem associated with intensive animal production. Animal manure can increase farmers' profitability by providing a lower cost alternative supply of soil nutrients and usually enhances soil biophysical characteristics (McGrath et al., 2010). According to many previous agronomic studies, animal manure was found to be equally effective as commercial fertilizers for the row crops and forage production (Kwaw-Mensah and Al-Kaisi, 2006; McAndrews et al., 2006; Loria et al., 2007; Paschold et al., 2008; Chantigny et al., 2008). Agronomic benefits from applying swine effluent have also been reported, including the build-up of macro- and micro-nutrients (N, P, K, S, Ca, Mg), increased soil organic carbon, enhanced soil fertility and soil aeration, and increased beneficial microorganisms. Moreover, some studies on row crops and forages found that animal manure can be an agronomically viable substitute for inorganic fertilizers (Adeli and Varco, 2001; Brink et al., 2003; and Adeli et al., 2005).

In Oklahoma, areas outside of these nutrient-dense watersheds are typically composed of soils that are nutrient poor and low in organic matter and pH, resulting in overall poor agronomic conditions; thus, such soils in these nutrient deficient areas would benefit most from litter applications (McGrath et al., 2010; Adeli et al., 2009). However, the cost of transportation is the most limiting factor to movement of litter to nutrient-deficient areas since manure is typically too bulky to transport over long distances (Payne and Smolen, 2006). Liquid swine manure often cannot be hauled more than 25 miles, after which other manure or commercial fertilizer becomes a more economical choice. A study conducted in Alabama determined that litter can only be cost effectively transported up to 263 km from the production facility. The Alabama study showed that the 29-county region could not utilize the amount of litter produced due to high shipping costs that constrained litter movement (Paudel, 2004). Cost-share programs have been successfully implemented in both Arkansas and Oklahoma to help defray litter transportation costs. However, due to state and federal budget cuts and successful development of markets for litter, these programs

are being phased out. Poultry litter has longer distances over which it can be profitably shipped compared to liquid swine manure.

One potential solution to help decrease the cost of litter transportation and allow for greater hauling distances is reducing litter mass. Traditional composting of animal manure will cause a mass reduction of 30 to 50% (Eghball et al., 1997; Rynk, 1992) due to organic carbon (C) oxidation to carbon dioxide (CO₂). However, traditional composting of litter is not always a viable option since this is a time, energy, and labor consuming process, in addition to application of C rich materials intended to decrease N volatilization. An increase in the C:N ratio occurs due to the typical application of materials with C:N ratios higher than the litter (i.e. "bulking agents"); this increase in C:N makes the material less desirable as an agronomic fertilizer by reducing the plant available nitrogen (PAN) content of the material. Since litter value (monetary) is currently based on the amounts of N, P, and K contained in "as is" litter, any increase in nutrient concentration and reduction in moisture content will increase litter value on a weight basis and increase the efficiency in which nutrients could be transported (Carreira et al., 2007).

This increase in value would allow for greater transport distances per unit mass of litter. In addition, a decrease in litter mass or increase in P concentrations via drying or organic matter decomposition would simply reduce the total mass of material needed to be transported. Thus, for poultry litter there is an opportunity to reduce litter mass and increase nutrient concentrations with little monetary and labor inputs for the purpose of reducing litter transport costs and increasing hauling distances.

Although the profitability of manure is critical to ensure that producers would be willing to apply animal waste, there has been only limited research in semiarid agroecosystems on the profitability of animal waste application. In particular, there has been limited testing on the long-term, repeated applications of animal manures in cropping systems. One objective of the chapter will present the findings from field experiments in Oklahoma that measured the yield efficacy of swine manure and beef manure, and poultry litter relative to commercial fertilizers. An economic model will be constructed for each type of manure to test its profitability, i.e. measuring its economic viability as a substitute for commercial fertilizer. Results will be presented and discussed, including a cross-cutting assessment of the differences among the alternative types of manure.

A second objective of the chapter is to determine the potential for transporting animal waste to producers in the surrounding area. To fill in this gap, a transportation model was developed using GIS that predicts animal waste movements in Oklahoma based on the supply of animal manure and demand centers. The transportation model was parameterized using the results of the field trials. Our chapter also presents findings from a poultry litter study that tested composted poultry litter, which is a less bulky form of litter that can be transported over longer distances.

The issues to be explored in this chapter, while having regional significance and importance in Oklahoma, will also resonate with national and international readers as well. Issues of animal waste management are present in other parts of the U.S., e.g. Iowa and North Carolina, and increasingly in other parts of the world such as China. At the regional level, the chapter has importance since the Oklahoma Panhandle has a limited and irregular surface water source, and elsewhere in Oklahoma groundwater is getting competitive among alternative users such as livestock production, crop irrigation, and human consumption. It is important to utilize the water and the nutrients in the manure by developing the proper animal waste management and application

practices to protect waterways. So, the third objective of this chapter is to present how Oklahoma has managed animal waste over the past two decades. The comparison among the alternative sources of animal manure will be of interest to policy makers in other regions since the issues of animal waste management are present in most parts of the world.

2. Methodology

This section utilizes results from field experiments conducted at several sites in Oklahoma that tested the efficacy of manure when applied on different types of crops and forage grasses. This includes experiments on animal waste from swine, beef, and poultry producers. The data collected from the field experiments enables a direct comparison between animal waste and inorganic fertilizers.

2.1 Swine and beef manure efficacy trials: Western Oklahoma

A long-term field experiment was conducted from 1995 to 2007 at the Oklahoma Panhandle Research and Extension Center (OPREC) near Goodwell, Oklahoma (36°35 N, 101°37 W; elevation) to test the efficacy of applying alternative nutrient sources on corn and four types of forage grasses (Park et al., 2010). Annual precipitation and temperature at the Goodwell station are well representative of the climate in the Southern High Plains, with an average rainfall of 435 mm per year and an average temperature of 13.2°C, respectively. The field experiment was established on a Gruver soil series, which is classified as a fine, mixed, superactive, and mesic Aridic Paleustoll soil with a 0 to 2% slope. The Gruver soils are also typical of conditions prevailing in the region in and around the experiment station.

The experimental design for corn was a randomized, complete block design with three replications of each of the main treatment effects, nitrogen source (NS) and nitrogen rate (NR). Each of three N sources, anhydrous ammonia (AA), beef manure (BM), and swine effluent (SE), were applied at equivalent nitrogen rates of 0, 56, 168, and 504 kg N ha⁻¹ yr⁻¹. Nitrogen application levels were selected on a maximum amount of swine effluent applied at 0.0205 ha-m yr⁻¹ as part of the waste management system for swine confined animal feeding operation units in the region, which supplied approximately 504 kg N ha⁻¹ yr⁻¹. Equivalent N rates of 504 kg N ha⁻¹ yr⁻¹ for AA and BM were also included in the experiment to maintain a balanced design, even though they are higher than recommended application rates. Hence, to provide meaningful comparisons with AA and BE, other NR were included. The N rate of 168 kg N ha⁻¹ yr⁻¹ is consistent with recommended N rates to satisfy yield goals in the region (Zhang and Raun, 2006), and a low N rate of 56 kg N ha⁻¹ yr⁻¹ was included to provide additional NS comparisons.

The main treatment effects were arranged in a split-plot design, with NS on each of the main plots, and the equivalent NR on the corresponding subplots. Before the experiment, continuous wheat had been grown on the test plots for several years. Nutrient levels for macronutrients (P and K) and micronutrients (Mg, Ca, S, Fe, and Mn) were found to meet or exceed plant requirements, so these nutrients were not added. Before the start of the experiment in 1995, soil P was sufficient, with an initial value of 73 kg ha⁻¹, which exceeded the recommended P level of 32 kg ha⁻¹, and remained above this level throughout the experiment (Zhang and Raun, 2006). Soil N levels were 141 kg ha⁻¹ before the start of the experiment, which were about 50 kg ha⁻¹ below the recommended soil N level of 190 kg ha⁻¹ (Zhang and Raun, 2006). Soil pH levels were not adjusted because they would interfere with

one of the long-term objectives of the experiment, which was to evaluate the cumulative effects of repeated nutrient applications on crop yields and soil properties (including pH) across different NS.

The experimental design for the grass forage study was a randomized complete block design with three replications of each of the main treatment effects, NS and NR. Each of the nitrogen sources, anhydrous ammonia (NH₃), BM, and SE, were applied at equivalent nitrogen rates of 0, 56, 168, and 504 kg N ha⁻¹ yr⁻¹. A total of 28 grass forage production strategies were also tested using an experimental design that included combinations of three factors: forage type, N source, and N rate. This design included four grass species (Bermuda grass, buffalo grass, orchard grass, and wheatgrass), four N application rates (0, 56, 168, and 504 kg N per ha), and two sources of nitrogen fertilizers (swine effluent and urea).

The experimental plots used a split-plot design with four replications for each of the 28 grass production strategies. In the first year of the experiment, each plot was randomly assigned to one of the strategies. Since residual effects (e.g. nutrient carry-over) were expected to have a significant effect on production outcomes, each strategy was maintained in the same plot throughout all eight years of the experiment. Swine effluent was obtained from a local anaerobic single stage lagoon near the research station, the same type of effluent available to producers. Swine effluent and urea were applied at equivalent N rates of 56 and 168 kg N per ha after the first monthly cutting in June. The 504 kg N per ha rate was split into two applications; the first application came after the first cutting in June and the second just after the second cutting in July. All plots were fully irrigated under a center-pivot irrigation system following standard practices used by producers in the region. The swine effluent was field applied through the center pivot system as part of the June and July irrigation water applications.

2.2 Poultry litter efficacy trials: Eastern Oklahoma

A short-term (3 yr) study was established at two distinct locations in the spring of 2007 with two locations: Oklahoma State University's Eastern Oklahoma Research Station located south of Haskell, OK (35° 44' 46" N, -95° 38' 23" W) and at a site located west of Aline, OK in Woods County (36° 29' 25" N, -98° 40' 24" W). The three year experiments tested the efficacy of poultry litter on sweet sorghum and bermudagrass, each having an importance in the region as a source of animal feed and potential biofuel feedstock (Penn et al., 2011). Test plots were established on a Taloka fine mixed, active, thermic, mollic, Albaqualfs at Haskell and Eda mixed, thermic Lamellic Ustipsamments at Woods. A randomized split-plot design was employed similar to design of the swine effluent trials in Western Oklahoma discussed previously. Inorganic commercial fertilizer was applied at equivalent N, P, and K rates of the poultry litter based on the prior analysis of the litter using urea, di-ammonium phosphate, and potash. Degraded litter was applied at the same N, P, and K rate of the fresh poultry litter. The Haskell site has on average 215 growing days, with an average temperature of 15.5°C, and 1130 mm of precipitation a year. The Aline site has on average 191 growing days, with an average temperature of 14.3°C, and 683 mm of precipitation a year.

2.3 Transportation model of animal waste movements

An animal waste transportation model was constructed to evaluate the economic benefits of applying litter, swine effluent, and beef manure as a substitute for chemical fertilizer (Penn et al., 2011). The transportation model was constructed utilizing the results of the field trials

discussed above. Animal waste movements are projected in the model by minimizing shipping costs between source and destination, i.e. poultry producers supplying litter and farms demanding the contained nutrients. In addition to the transportation costs, handling and applications costs are also included in the model for animal waste movement. Benefits are measured as the cost of applying macronutrients (NPK) using animal waste compared to chemical fertilizers. Field application rates for animal waste were obtained based on the results of the field efficacy trials.

The transportation model projects animal waste movements by minimizing shipping costs between source and destination, i.e. between animal producers supplying animal waste and farms demanding the contained nutrients. The cost of transporting animal waste from source i to destination j is given by the following equation:

$$\text{TRNSP COST} = \sum_i \sum_j \sum_t D_{ij} C_{ij} Q_{ijt} X_{ijt} \quad (1)$$

Where D_{ij} is the distance from i to j , X_{ijt} is the binary decision variable that determines whether animal waste is shipped in year t ($X_{ijt}=0$ no shipment, $X_{ijt}=1$ shipment), Q_{ijt} is the quantity of animal waste shipped in year t , and C_{ij} is the unit cost of transporting animal waste from i to j in year t . In Oklahoma, this requires moving litter from the eastern part of the state where poultry operations are concentrated to producers in the central part of the state where wheat and hay production is primarily located, and likewise moving swine effluent and beef manure in the western part of the state to farms in and around the Panhandle. In addition to the transportation costs, handling and applications costs are also included in the model for poultry litter, swine effluent, and beef manure. When combined with the transportation costs from Equation 2, the total cost of transporting, handling, and field applying animal waste is given by the following:

$$\text{TOTAL COST} = \sum_i \sum_j \sum_t (D_{ij} C_{ij} + H_{ij} + A_{ij}) Q_{ijt} X_{ijt} \quad (2)$$

where H_{ij} and A_{ij} are the handling and field application costs for poultry litter for each unit of poultry litter shipped from source i to destination j .

Constraint relationships were included in the model to ensure compliance such that the accumulated soil P levels from applied animal waste were held under 32.5 mg kg^{-1} . Using similar notation to Equation 2, the soil phosphorus constraint equation is given by the following inequality:

$$\sum_i \sum_t X_{ijt} Q_{ijt} \text{PHOS} \leq \overline{P_{\text{soil}}} \quad \text{for all } j \quad (3)$$

Where PHOS is a coefficient that relates the quantity of animal waste applied at site j in year t to the long-run accumulation of phosphorus in the soil and $\overline{P_{\text{soil}}}$ is the upper limit on soil phosphorus levels. Optimum soil test P concentration for agronomic production in OK is 32.5 mg kg^{-1} (M3-P soil extraction; Mehlich, 1984). For P demand and crop production, it was assumed that no P would leave the farms receiving litter; this provided a “worst case scenario” for moving either poultry litter, swine effluent, or beef manure. The increase in soil test P with litter applications was estimated using relationships developed for Oklahoma soils (Davis et al., 2005).

Economic benefits were determined in the transportation model by the cost savings in applying equivalent nutrient levels from animal waste versus commercial fertilizer sources according to the following equation:

$$\text{BENEFITS} = \sum_i \sum_j \sum_t Q_{ijt} \Phi_{\text{NPK}} \text{PRC}_{\text{NPK}} X_{ijt} \quad (4)$$

Where Φ_{NPK} is the transformation coefficient governing the content of NPK per unit of animal waste and PRC_{NPK} is the vector of N, P, and K prices. This valuing approach also enabled a direct comparison between commercial fertilizer and animal waste. Animal manure demand was estimated based on its use as a substitute for N, P, and K from commercial fertilizer. Poultry litter applications were applied in the model based on observed crop and hay acreage at the county level (NASS 2009) and achievement of 32.5 mg kg⁻¹ M3-P, which established an aggregate demand for P. Current average soil P levels were estimated using soil test samples from Oklahoma State University's Soil Testing Laboratory, which contains records of 65,000 soil samples.

Consistent with Carreira et al. (2007), poultry litter, swine effluent, and beef manure was valued using commercial fertilizer prices to establish nutrient prices for N, P, and K (Oklahoma State University Nutrient Management; NPK, 2010). The model used results from previous field experiments discussed in the previous section to value poultry litter, swine effluent, and beef manure on a weight basis (i.e. the estimate of Φ_{NPK}) based on the measured concentrations of N, P, and K in each type of animal waste. Poultry litter's macronutrient contents for NPK (77% dry matter) were measured at 3.15% for nitrogen, 3.05% for phosphorous, and 2.50% for potassium. For swine effluent, NPK contents were measured at 0.21%, 0.05%, and 0.25%, respectively. At 62% dry matter content, beef feedlot manure had NPK contents of 1.2%, 1.05%, and 1.25%. Transportation, handling, and field application costs for poultry litter used in the economic model (see Equation 3) were obtained from Carreira et al. (2007), with values of $C_{ij} = \$0.10 \text{ Mg}^{-1} \text{ km}^{-1}$, $H_{ij} = \$18.73 \text{ Mg}^{-1}$, and $A_{ij} = \$ 7.72 \text{ Mg}^{-1}$. The corresponding values for swine effluent and beef manure were obtained from Park et al. (2010).

The transportation model was solved by maximizing the difference between the BENEFITS and COSTS equations subject to maintaining soil P levels within the prescribed limits dictated by Equation 3. The General Algebraic Modeling Systems (GAMS) software package was used to find the optimal solutions to the transportation modeling formulation given by Equation 1 through Equation 4. Results were then linked to the Arc-Maps GIS system where maps were created to present results of the transportation flows. The transportation model was solved under two scenarios. In the first scenario, poultry litter was prepared conventionally. In the Compost Scenario, all of the poultry litter was presumed to be prepared as compost. While complete adoption of compost is not anticipated, the scenario establishes the upper limit on the benefits of compost.

2.4 Statistical analysis

Analysis of variance models (ANOVA) were constructed for the crop and forage yields and corresponding economic returns using the SAS PROC MIXED routine (SAS Institute, 2002). For all of field studies, ANOVA models were used to determine if there were significant differences among main treatment effects, which varied between each study. In

the poultry litter study, chemical properties ($p = 0.05$) between the fresh litter (day 0) and degraded litter (i.e. day 60) were tested. The effects of nitrogen source and nitrogen rate were included in the model as fixed effects along with covariates rainfall and irrigation. The small scale poultry litter storage had year as the blocking factor (three years) and two different treatments; normal litter and alum amended litter. The swine effluent and beef manure experiments in Western Oklahoma tested nitrogen source and nitrogen rate. The economic profitability of each nitrogen source was calculated as the gross income (corn price \times yield) minus total specified costs. Sensitivity analysis on the economic models was also obtained to illustrate using break-even analysis how alternative prices would affect profitability.

3. Results

The results from the field trials in Western Oklahoma showed that both swine effluent and beef manure generated significantly higher corn yields than anhydrous ammonia (Figure 2). The highest corn yield was found when beef manure was field applied at a rate of 168 kg per ha, but the yield was not statistically different from those with swine effluent when applied at that same rate (Figure 2). While at the lower nitrogen rate of 56 Kg N per ha no effect of nitrogen source on corn yield was found, greater mean separations were found among the nitrogen sources when the rate of nitrogen application was increased. At the highest nitrogen application rate of 504 Kg N per ha, swine effluent generated the highest corn yield, followed by beef manure and then anhydrous ammonia. The superior performance of the animal manures (swine effluent and beef manure) over commercial fertilizers can be explained by enhanced soil components such as the addition of micronutrients and organic matter, and improved soil pH levels.

In terms of forage production systems, higher dry matter yields were observed in urea than swine effluent for the summer forage grasses, whereas swine effluent had higher forage yields than urea for the winter forage grasses. However, in both the winter and summer grasses the yield differences between urea and swine effluent were not statistically significant according to the ANOVA model. Unlike what was found in the corn experiments, there was no separation of mean yields between swine effluent and urea as the application rate of nitrogen was increased. The overall conclusion of the forage grass study was that no significant difference in dry matter yield was found between swine effluent and urea, which provides empirical evidence that swine effluent can be an equivalent substitute for the commercial fertilizer for forage production systems commonly used in the Panhandle region.

Economic comparisons among the alternative nitrogen sources tested in the Western Oklahoma field trials are presented in Figure 3. Both beef manure and swine effluent generated higher economic returns than anhydrous ammonia under corn production. The highest economic return was found with swine effluent, but its returns were not significantly different from those of beef manure. Less separation among mean economic returns was found at the lower and middle rates of nitrogen application, 56 and 168 Kg N per ha, but swine effluent generated the highest economic return at the highest rate of nitrogen application followed by beef manure and anhydrous ammonia.

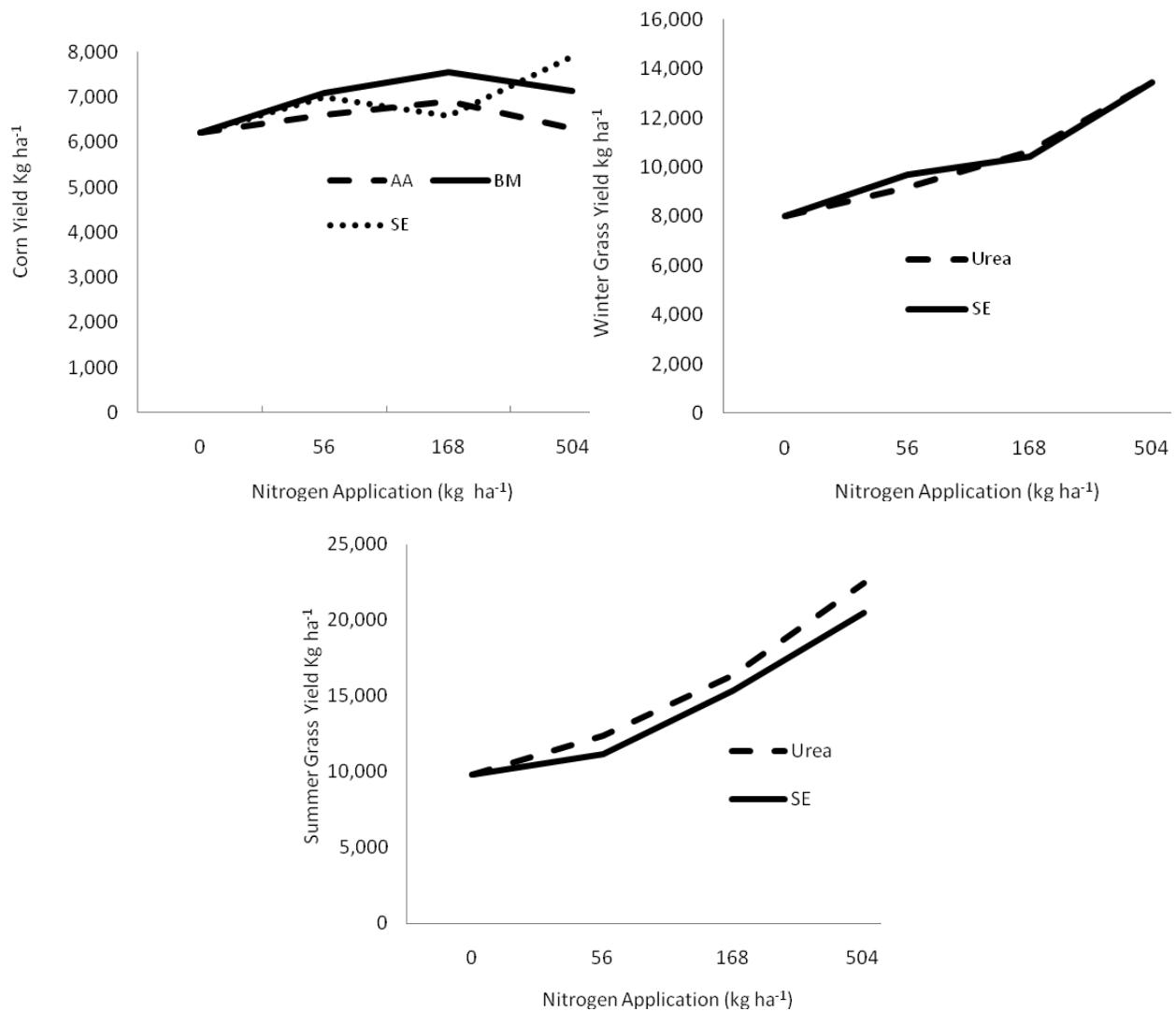


Fig. 2. Results of the swine effluent and beef manure field trials in Western Oklahoma on corn, winter grass forage (orchard grass and wheatgrass), and summer grass forage (bermudagrass and buffalo grass).

Under the forage production systems, swine effluent generated significantly higher economic returns than urea in the summer forage (Figure 3). Greater mean separations of economic returns between swine effluent and urea were found as the rates of nitrogen application increase. In the winter forage, higher economic return was found in swine effluent but was not significantly different from that in urea. Also, there was no mean separation of economic returns between swine effluent and urea as the N rates increase.

In summary, the field experiments in Western Oklahoma show that swine effluent and beef manure can be economically viable substitutes for commercial fertilizers when applied on corn, one of the major crops in the region. Both types of animal manure can also be applied economically on forage grasses, crops that commercial fertilizers are typically applied on less intensively since they are not as profitable. Hence, swine effluent and beef manure can benefit producers in the Oklahoma Panhandle by generating higher yields and economic benefits compared to commercial fertilizer.

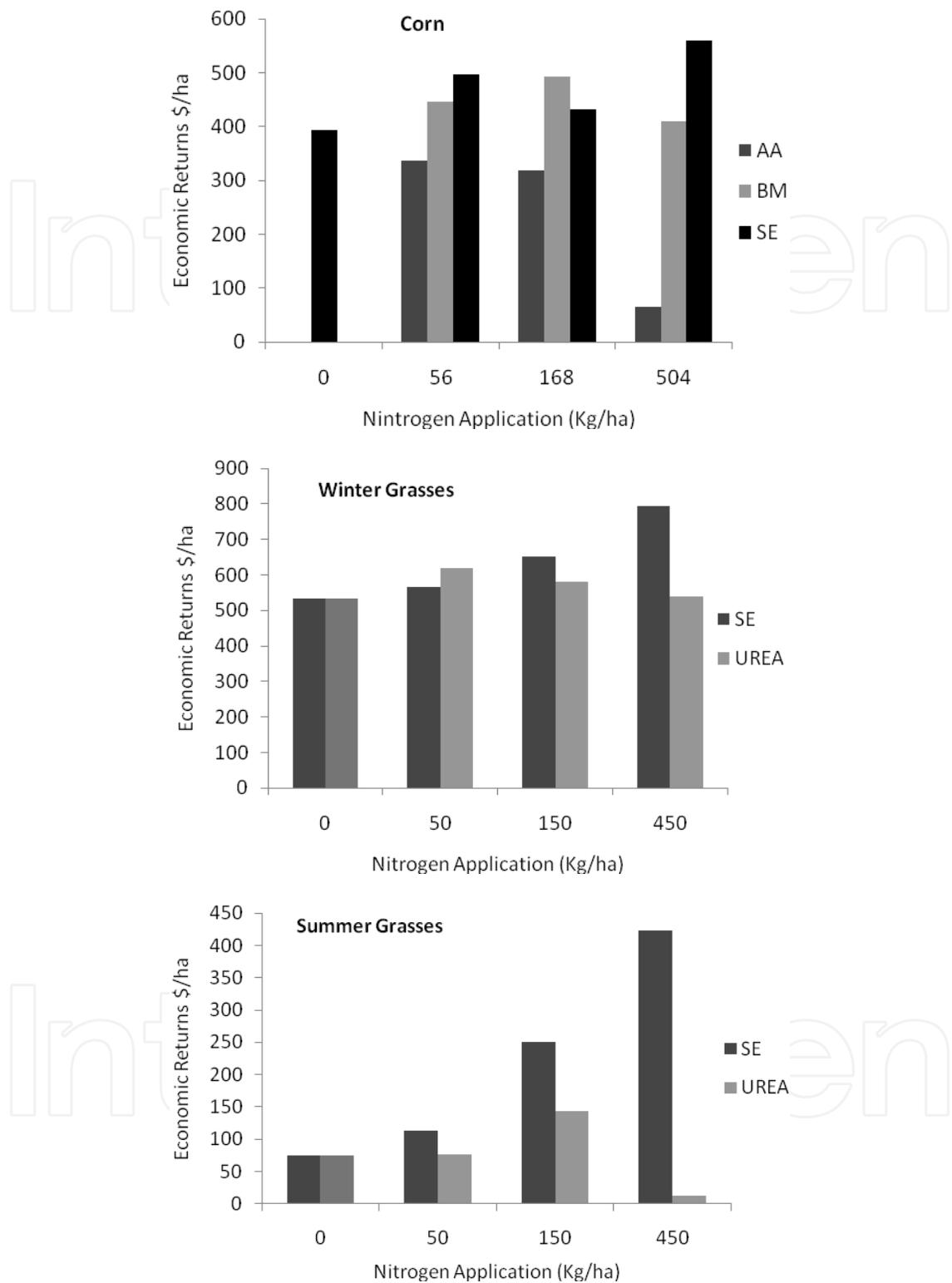


Fig. 3. Economic comparisons among swine effluent, beef manure, anhydrous ammonia, and urea when applied on corn, winter grass forage (orchard grass and wheatgrass), and summer grass forage (bermudagrass and buffalo grass). Each panel in the figure summarizes the findings of the field trials in Western Oklahoma from several years of field trials (1999-2007)

3.1 Poultry litter

Poultry litter was found to be similar to commercial fertilizer when applied at commensurate levels (Figure 4). Although sweet sorghum and Bermudagrass yields had slightly higher values on the commercially fertilized plots compared to the poultry litter plots, the difference was sometimes not statistically significant ($P>0.05$). Sweet sorghum yields reached 19.5 Mg ha^{-1} when 240 kg ha^{-1} of nitrogen was applied with commercial fertilizers, and with poultry litter sweet sorghum yields were 15.8 Mg ha^{-1} . Averaged over 3 years, bermudagrass biomass yields responded to fertilizer rate in a linear fashion for both fertilizer types ranging from $2.95\text{-}5.82 \text{ Mg biomass ha}^{-1}$ (Figure 4). The 2008 and 2009 growing season was extremely dry with significantly higher yield for inorganic fertilizer sources than poultry litter. This was likely due to the lack of mineralization due to the dry conditions. On the other hand, 2007 bermudagrass biomass yield was not significantly different between the two nutrient sources; this was likely due to the fact that 2007 was a wet year and moisture was not limiting for mineralization to occur.

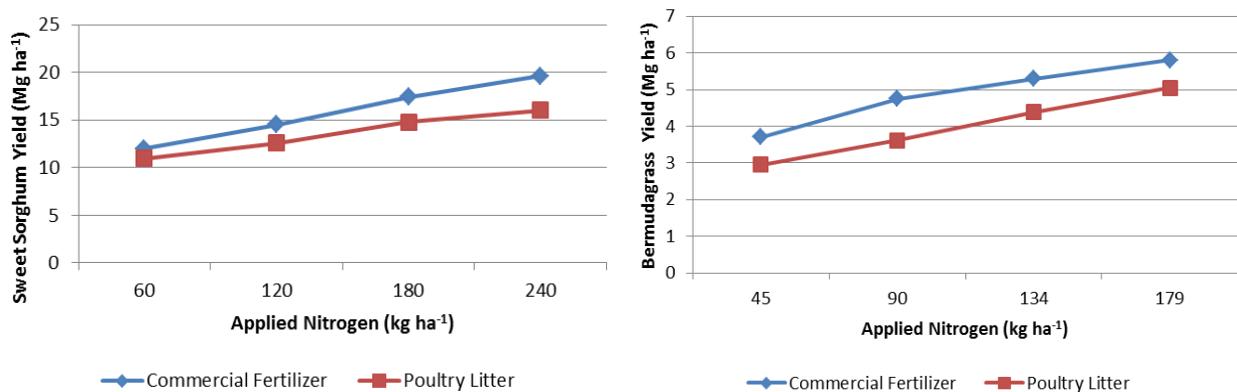


Fig. 4. Response of nitrogen application and source (poultry litter and commercial fertilizer) on sweet sorghum and Bermudagrass yield based on three years of field trials in Eastern Oklahoma. Note that for each nitrogen rate, an equivalent amount of phosphorus and potassium was also applied among the two nutrient sources. Results of the field trials showed no significant difference in yield among the nutrient sources.

Haskell sweet sorghum biomass yields in 2007 and 2009 were not substantially different due to non-ideal conditions, while 2008 produced significantly higher yields and was the only year with a linear response to N and significant differences between fertilizer type as the inorganic outperformed the litter. Yield over the 3 years ranged from $9.1\text{-}29.7 \text{ Mg ha}^{-1}$. Woods county sweet sorghum produced a linear result to N application with no difference between fertilizer types with yield ranging from $4.9\text{-}7.9 \text{ Mg ha}^{-1}$. No significant difference between fertilizer types was observed for nutrient uptake among both crops and sites. Nutrient removal appeared to be controlled by the rate of fertilizer applied and total biomass removed.

The field trials also tested degraded litter and found that it also provided equivalent agronomic performance to commercial fertilizer when applied on equivalent nitrogen and phosphorus basis (Penn et al., 2011). Use of poultry litter appears to be a good alternative to inorganic commercial fertilizer especially when P and K deficiencies are present and ideal mineralization conditions occur.

The results of the field trials in Eastern and Western Oklahoma are important since they indicated that animal manure, when applied at equivalent rates with commercial fertilizer,

performs equally well as commercial fertilizer. Moreover, the field trials in Western Oklahoma suggest that animal manure can provide enhanced agronomic performance due to increased levels of micronutrients and the ability to maintain soil pH. Such agronomic benefits are also anticipated to be present in poultry litter. For example, bermudagrass and sweet sorghum plots treated with poultry litter result in a significantly higher soil pH after three years of annual applications compared to commercial fertilizer treatments. In addition, sweet sorghum litter treated plots possessed a significantly greater soil aggregate stability (indicator of soil quality) at high application rates compared to commercial fertilizer. Given the substitutability of animal manure with commercial fertilizer, economic benefits can be achieved if manure can be marketed, transported, and field applied at lower cost than commercial fertilizer. The next section presents the anticipated benefits from animal manure based on the findings of the Oklahoma field trials and the economic model described above.

3.2 Transportation model

Results of the transportation model project the optimal movement of Oklahoma's annual production of animal manure over a 50 year period (Figure 5). As illustrated in Figure 2, the movement of animal manure is greatly determined by the shipping costs and the location of the animal producers. Poultry litter is shipped the furthest and swine effluent the shortest. poultry litter is generally shipped westward from the eastern portion of Oklahoma in and near the Illinois River watershed, to locations that reach up to 200 miles away. By year 25, the model projects poultry litter movements that reach roughly one-half of the state (Figure 5). Swine effluent, due to its bulkiness, is primarily confined to the Oklahoma Panhandle region. Movements of beef manure are also primarily concentrated in the Panhandle, but there are a couple of other areas in the state with noteworthy movements of beef manure.

Poultry litter would provide the largest movements of nitrogen and phosphorus over the first 10 years, with 58,457 metric tons of nitrogen and 24,712 metric tons of phosphorus delivered to producers (Table 1). Swine effluent would deliver nearly the same quantity of nitrogen as poultry litter over the first ten years, 58,245 metric tons, however the swine effluent would deliver significantly less phosphorus, 6,055 metric tons (Table 1). This is simply due to the fact the swine effluent contains very little P compared to poultry and beef manure. With the largest quantity of macronutrients delivered, poultry litter would generate the greatest economic benefits, \$37.4 million, which corresponds to an average benefit of \$3.75 million per year. The model projects that swine effluent would result in \$28.2 million in economic benefits and beef manure an additional \$6.48 million (Table 1). The total economic benefits to Oklahoma producers from the movement of all three types of animal manure would be \$72.0 million (Table 1).

Animal waste movements change noticeably over the next fifteen years. By year 25, swine effluent would account for the largest movement of nitrogen, while poultry litter would still be the largest deliverer of phosphorus (Figure 6; Figure 7). According to the model results, swine effluent would deliver 145,613 metric tons of nitrogen to Oklahoma producers, compared to the 103,715 metric tons of nitrogen that that poultry litter is projected to deliver (Table 1). Swine effluent would deliver 40.4% more nitrogen in year 25 than poultry litter, reversing the trend that occurred during the first 10 years.

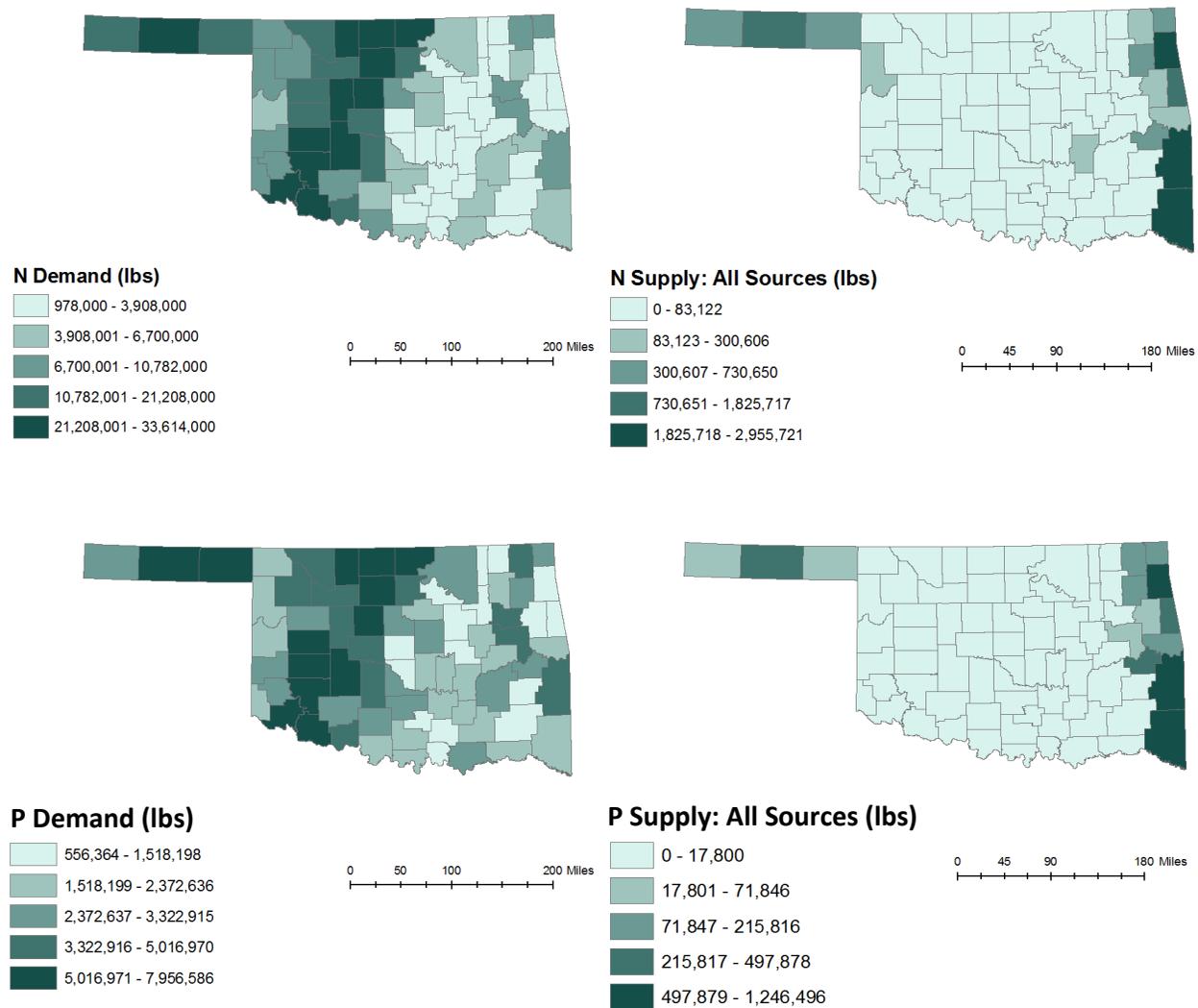


Fig. 5. Demand and potential supply of nitrogen and phosphorus in the state of Oklahoma from all three major animal waste sources, poultry litter, swine effluent, and beef manure.

While poultry litter would still be the largest supplier of phosphorus to producers, delivering 43,844 metric tons of phosphorus to producers by year 25, its' annual delivery has decreased compared to swine effluent and beef manure. For instance, in the first 10 years of the analysis poultry litter delivered an average of 2,417 metric tons of phosphorus per year. Between years 10 and 25, however, phosphorus deliveries in Eastern Oklahoma declined to an average of 1,275 metric tons per year. During that same 25 year period, both swine effluent and beef manure delivered the same quantity of phosphorus each year, 605 and 96 metric tons (Table 1). This decline in phosphorus movements from poultry litter is a result of the combination of two factors: poultry manure has a higher P concentration compared to swine and beef manure, and P is able to "build up" in soils (unlike N) to a point in which an agronomic optimum P level is achieved (32.5 mg kg^{-1} Mehlich-3). In other words, soils in Eastern Oklahoma will reach the agronomic P optimum level more quickly, preventing further delivery of manure. This requires poultry litter movements shift further west, increasing transportation costs.

Time (Yrs)	Conventional Litter Scenario				Degraded Litter Scenario			
	Convent Litter	Swine Effluent	Beef Manure	Total	Degraded Litter	Swine Effluent	Beef Manure	Total
	<u>Animal Waste Delivered (metric tons)</u>				<u>Animal Waste Delivered (metric tons)</u>			
5	927,887	57,898,488	105,315	58,931,689	927,887	57,898,488	105,315	58,931,689
10	1,855,774	115,796,975	210,629	117,863,379	1,855,774	115,796,975	210,629	117,863,379
25	3,292,537	289,492,439	526,573	293,311,548	3,912,093	289,492,439	526,573	293,931,104
50	3,658,328	117,626,890	1,053,146	122,338,364	3,891,780	491,092,266	1,053,146	496,037,192
	<u>Nitrogen Delivered (metric tons)</u>				<u>Nitrogen Delivered (metric tons)</u>			
5	29,228	29,123	1,264	59,615	29,228	29,123	1,264	59,615
10	58,457	58,245	2,528	119,230	58,457	58,245	2,528	119,230
25	103,715	145,613	6,319	255,647	123,231	145,613	6,319	275,163
50	115,237	247,016	12,638	374,892	122,591	247,016	12,638	382,245
	<u>Phosphorus Delivered (metric tons)</u>				<u>Phosphorus Delivered (metric tons)</u>			
5	12,356	3,027	483	15,866	12,356	3,027	483	15,866
10	24,712	6,055	966	31,732	24,712	6,055	966	31,732
25	43,844	15,137	2,414	61,395	52,095	15,137	2,414	69,645
50	48,715	25,678	4,828	79,221	51,824	25,678	4,828	82,330
	<u>Economic Benefits (\$ million)</u>				<u>Economic Benefits (\$ million)</u>			
5	24.2	14.1	3.2	41.5	29.9	14.1	4.03	48.1
10	37.4	28.2	6.48	72.0	46.9	28.2	8.06	83.1
25	46.2	70.5	14.8	131.4	62.8	70.5	18.7	151.9
50	48.5	120.0	21.3	189.8	65.0	119.9	29.2	214.3

Source: Authors' calculations.

Table 1. Potential animal waste transport and economic benefits of beef manure, swine effluent, and poultry litter relative to commercial fertilizer as determined by the transportation model.

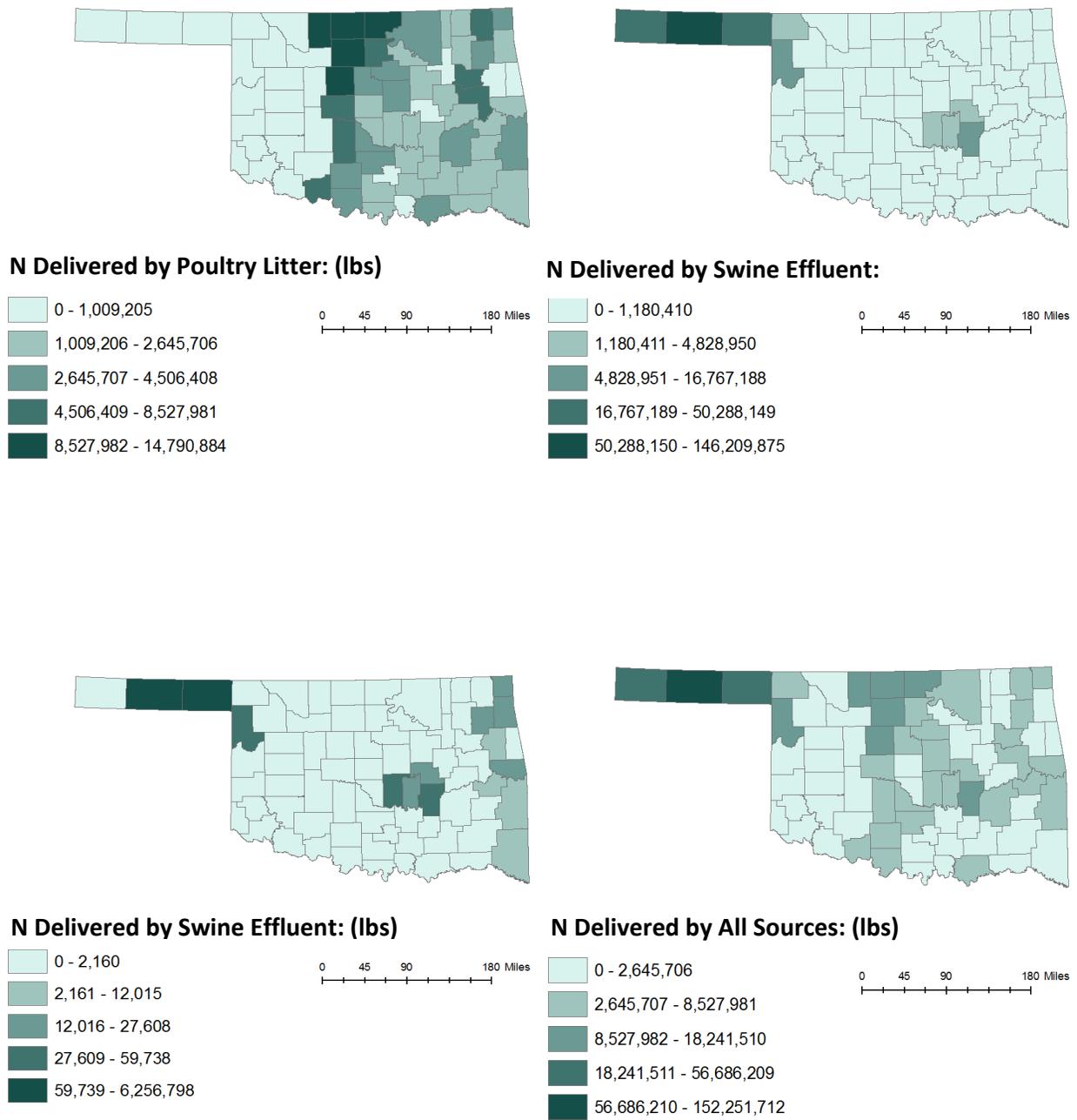


Fig. 6. Nitrogen delivered by the major animal waste types when field applied on crop and pasture lands over the span of 25 years.

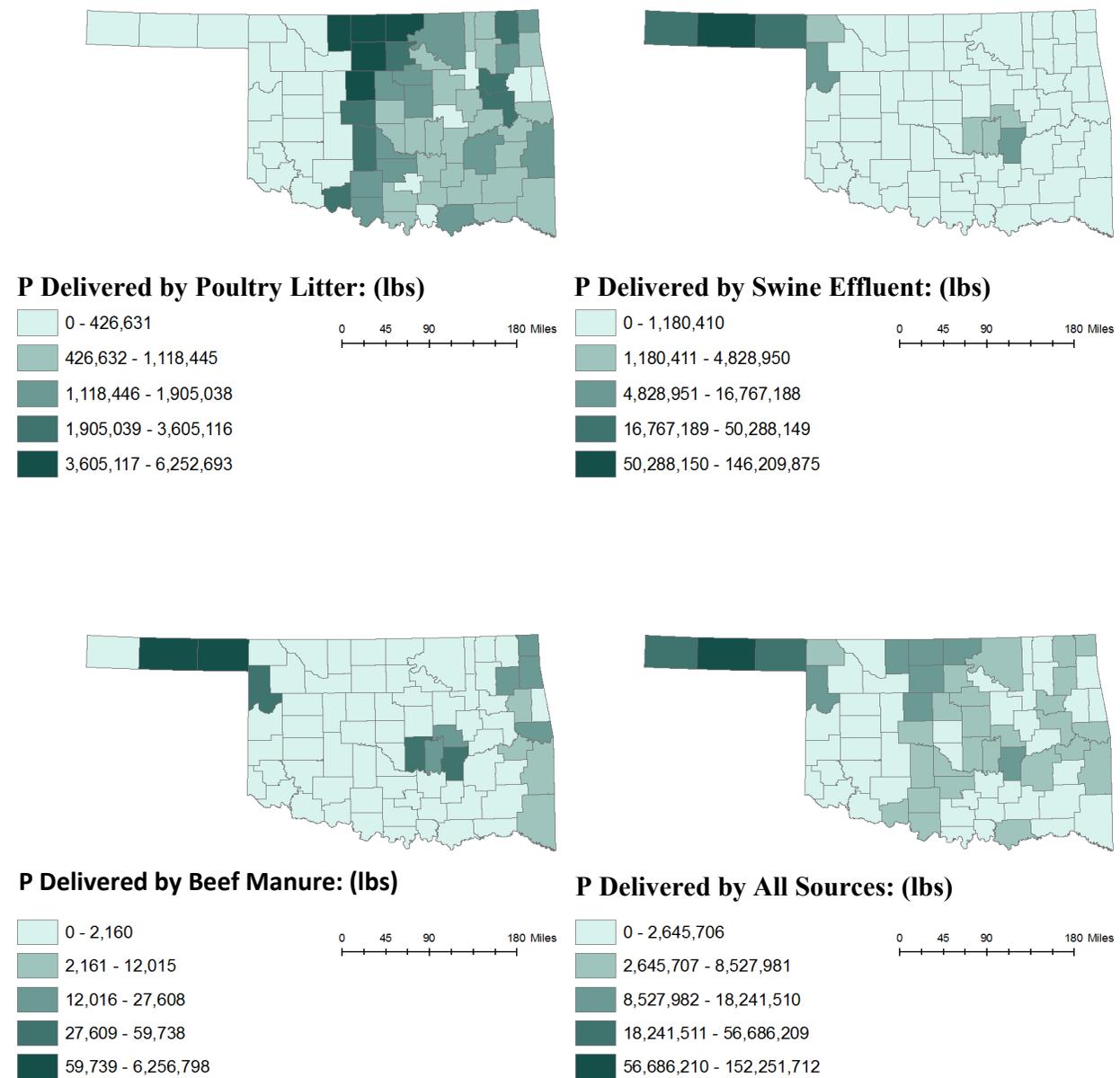


Fig. 7. Phosphorus delivered by the major animal waste types when field applied on crop and pasture lands over the span of 25 years.

The long-term buildup of soil P concentration in Eastern Oklahoma, and its effect on limiting the movement of poultry litter, is even more apparent by year 50. In the transportation model, as soil P levels reached the state mandated threshold level of 32.5 mg kg⁻¹, poultry litter had to be shipped (if economically feasible) further west at increased transportation costs. This reduced the quantity of poultry litter transported off-farm and delivered to producers. By year 50, only 195 metric tons of phosphorus would be shipped from poultry producers in Eastern Oklahoma, due to the build-up of soil phosphorus (Table 1). This is a substantial decline compared to the first few years, when poultry producers delivered an average of 2,417 metric tons of phosphorus per year (Table 1). However, in Western Oklahoma, many soils are deficient in phosphorus and better able to

accept phosphorus applications. Typically, in Western Oklahoma swine effluent and beef manure applications are limited by nitrogen instead of phosphorus.

With the build-up of phosphorus in Eastern Oklahoma, the economic benefits of transporting poultry litter decline at a much faster rate than for swine effluent or beef manure (Table 1). This decline in benefits is evident by year 25, when swine effluent has for the first time, as reported in Table 1, the largest economic benefit. According to the transportation model, swine effluent would generate \$70.5 million in economic benefits by year 25, compared to \$46.2 million that poultry litter is projected to benefit. The difficulties in transporting poultry litter in an economical manner becomes even more apparent between years 25 and 50 in the model analysis, when the economic benefits from shipping poultry litter increases by only \$2.3 million. In comparison, swine effluent increased economic benefits generated by \$45.5 million during that same period of time, without any noticeable decline in benefits from one year to the next (Table 1).

3.3 Degraded litter

In the degraded litter scenario, degraded litter was placed in the transportation model to assess what impact it has on reducing transportation costs and increasing distances over which poultry litter can be shipped. According to the model results, degraded litter has a higher economic value than conventional litter. When equal quantities of degraded and fresh poultry litter are transported (70% dry matter), degraded litter has a greater value since its total phosphorus and potassium concentrations are larger than conventional litter, with only a small decrease in total nitrogen concentrations. According to the field trials on degraded litter (see above), both phosphorus and potassium can be transported at lower costs when shipped as degraded litter rather than conventional fresh litter. On a standard truck unit carrying 21.7 metric tons of litter (70% dry matter), degraded litter would be able to deliver 337 kg of phosphorus, significantly more than the 266 kg delivered by non-degraded litter, assuming P concentrations determined in the small scale study. Based on a typical hauling distance of 80 km, results of the field trials imply that degraded litter would increase economic benefits by \$180.96 per haul due to overall higher nutrient concentration. There would also be a substantial increase in the break-even distance over which litter could be profitably transported. Degraded litter could be transported as far as 416 km from the farm-gate, 82 km further than conventional litter's break-even distance of 334 km, when based on current market values of nitrogen, phosphorus, and potassium (Oklahoma State University NPK, 2010).

Degraded litter would also result in more efficient and effective movement of phosphorus out of nutrient limited watersheds that are concentrated primarily in Eastern Oklahoma (Table 1). Within the first five years, according to the transportation model, the seven major poultry producing counties in the Illinois River watershed would have produced and applied enough P on their soils to meet agronomic P requirements within their respective county. Once phosphorus thresholds are reached, poultry litter needs to be exported to non-poultry producing counties, generally located further west. Because of lower transportation costs and a greater break-even shipping distance, at some point in time degraded litter would have a larger market area and would be able to deliver larger quantities of P than conventional litter as indicated by the larger shipping quantities (Table 1). According to the transportation model, by year 25 degraded litter would be able to access producers in Western Oklahoma that would be out of the economic grasp of conventional litter due to the higher shipping costs (Table 1). The most noticeable effect of degraded litter appears after

year 25. At this time, conventional litter would have nearly reached its break-even distance, meaning that the cost of hauling litter beyond the break-even distance would exceed the litter nutrient value, rendering the movement of conventional unprofitable. As discussed in the previous section, there was little movement of poultry litter after year 25 (Table 1). For instance, over the last 25 years of the modeling scenario only 365,790 metric tons of conventional litter was transported. By comparison, in a single year an average of 185,577 metric tons of conventional litter was transported in the first 5 years.

Degraded poultry litter would remain an economically viable option for all 50 of the years included in the analysis (Table 1). As a result, a noticeably larger quantity of poultry litter would be shipped if producers used degraded litter rather than conventional litter. Over the 50 year modeling scenario time span, degraded litter would ship 3.89 million metric tons of poultry litter, 19.8% more than conventional litter's movement of 3.66 million metric tons. Degraded litter would also continue to generate economically important benefits from year 25 to year 50 (Table 1). Degraded poultry litter would provide the largest impact, reaching \$65.0 million over a 50 yr period. Conventional litter would generate an economic impact of \$48.5 million, \$16.5 million less than degraded litter, and corresponding to a difference of 34.0% compared to degraded litter (Table 1). Hence, conventional litter offers less economic potential than degraded litter since it is more costly to ship, ultimately limiting its ability to reach wayward points to the west.

4. Conclusions

For policy makers, Oklahoma's experience with animal waste management suggests the need for developing a program to recycle animal waste. This includes agricultural research to test the efficacy of animal waste products when field applied, as well as economics to assess its viability as a substitute for chemical fertilizers. According to the analysis presented in this paper, animal manure treatments provided a beneficial soil amendment for Oklahoma crops and forages with effects comparable to commercial fertilizer treatments. Furthermore, Oklahoma's animal producers should be able to transport animal waste products off-farm for a period of at least 25 years. Poultry producers are anticipated to encounter limitations on animal waste movements before swine or beef cattle producers. In Eastern Oklahoma, where the poultry industry is located, agronomic conditions are less favorable for the long-term application of phosphorus, and will more quickly reach state mandated limits on soil phosphorus concentration, due to the fact that litter contains more P compared to swine effluent and beef manure. In Western Oklahoma, soils generally possess less P and the locally available manure sources (swine and beef) contain less P than poultry litter, enabling long-term application of manure or effluent phosphorus with less potential buildup of soil phosphorus. Hence, swine producers and feedlot operators are anticipated to be able to transport animal waste off-farm for the entire 50 year period considered in the analysis of this chapter.

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