

Land Application of Swine Waste: Regulation and Producer Practices in Oklahoma

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1. Introduction

Animal manure management is an important issue currently receiving much attention from environmental regulators, the media, the public, and livestock producers. Manure management regulations are implemented in order to protect the environment and public health from the damage resulting from excessive nutrient concentration and runoff. Examples of this damage are the catastrophic lagoon spills from hog feeding operations in Iowa and North Carolina (Vukina, Roka, and Palmquist), the correlation of nutrients from livestock pollution with the recent *pfisteria piscicida* outbreaks along the east coast of the United States (U.S. EPA, 1998), the possible contribution of livestock manure to the April 1993 *chryptosporidium* contamination of the city of Milwaukee's drinking water (NRCD), and the possible links between dairy operations and poor water quality in Erath County Texas (TIAER).

One important aspect of manure management regulation attempts to reduce the over-application of manure to fields and thereby limit nutrient pollution runoff and seepage into surrounding surface and ground waters and prevent excessive phosphorous accumulation in the topsoil. Field runoff can occur when manure is spread in especially environmentally sensitive areas, when it is spread during very wet or very cold seasons, and when it is applied in too high a concentration for crop uptake. In principle, regulations can establish where, when, and in what concentrations manure is spread by setting setback distances, imposing restrictions on the time of year field applications occur and requiring the availability of "sufficient" land upon which manure is applied.

The excessive application of manure to fields is often attributed to land access constraints and also to the transportation costs involved in moving manure from storage to field application locations. As animal production has concentrated both vertically and geographically, especially

in swine production, it has been proposed that some larger operations do not have access to enough land to adequately spread manure. In addition, these larger operations which produce more manure must move their manure further and face higher manure distribution costs. These cost constraints are triggered by differences in operation waste management technology and in geographical characteristics and have important implications for manure management policy.

This paper develops some general hypotheses about producer practices relating to manure land application and examines current swine waste manure handling practices, land application methods, and potential land constraints based on a pilot survey of Oklahoma swine producers. This survey is undertaken to determine the actual importance of land and transportation cost constraints in this region and thereby assist policy makers in identifying potential causes for manure over-application. Based on a limited sample from our pilot survey, we find some evidence to support transportation-cost hypotheses about manure waste management: that transportation costs affect the distribution of swine waste on individual Oklahoma Farms.

The next section of the paper provides an overview of existing theory relating to the economics of land application of manure given possible land constraints and manure transportation costs. Section 3 then discusses regulation and policy relating to the land application of manure. Preliminary results of a pilot survey of Oklahoma swine producers are then presented in Section 4. We conclude with a discussion of the implications of Oklahoma manure management practices for policy design.

2. Factors Affecting Excessive Land Application of Livestock Waste Nutrients

Manure over-application is often attributed to two factors: land access constraints and manure transportation costs. Traditionally, smaller animal feeding operations have owned

enough cropland on which to spread their manure at or below agronomic levels, but as average operation size has grown, the amount of cropland owned has not expanded accordingly. A study by Letson and Gollehon found that the largest hog production operations housed 27 percent of total inventory but only controlled three percent of the total croplands located on production operations. Consequently, small and medium producers house 67 percent of inventory and controlled the remaining 97 percent of cropland.

Given the apparent discrepancy between manure generation potential and the available space for field application, it seems logical to suggest that environmental consequences of concentrated hog production can to some extent be attributed to a lack of land availability or to a lack of access to neighboring lands. Past studies on manure regulation have adopted this view and have suggested that it is important that formal links be established between manure producers and cropland owners in order to provide large operations with the land necessary to reduce nutrient concentrations (National Research Council, Govindasamy et. al., Trachtenberg and Ogg). A recent survey of hog producers undertaken by the USDA Economic Research Service provides a perspective on land availability which differs from the view of higher production concentrations resulting in application land deficits (McBride and Christensen). The ERS study suggests that operations are not facing a land availability nor a land access constraint as both small and large operations, on average, only apply manure on a small percentage (11% to 30%) of the land that these producers consider to be “available” for manure spreading. This result begs the question as to why such a small percentage of lands are being used especially when there is still a perceived problem of over-application of manure.

The ERS survey also discovers that the intensity of manure application in the U.S. Heartland region (measured as the ratio of animal units to application acres) ranges from 1.28 to

5.14 for small and large operations respectively. These intensities in the Southeastern United States range from 5.55 on small operations to 20.30 for larger operations. This suggests that larger operations are applying at a higher intensity than small operations, and in some cases, up to approximately 20 times more. Regulations differ between the Heartland states and the states in the Southeast and this may explain some of this observed difference in intensity, but large and small operations that are located within the same region are also applying at different intensities. Why is this true if they face similar nutrient management regulations and only a small percentage of the available lands are being used?

A hypothesis consistent with this incomplete use of available land for manure application is that the costs of manure transportation in terms of dollars and time lead to heavier manure application on convenient (nearby) land, and less application on distant land (Innes). This would be the case whether waste was transported by truck, tractor, or irrigation pipe to the field application locations. In his model, Innes assumes field application of manure consists of a continuum of applications radiating in concentric circles from the manure production (or storage) area at a distance r , and the maximum distance at which manure is applied is represented as \bar{r} . Each operation has a animals and each animal produces α units of manure. Manure is applied at various intensities within in each of these circles, where intensity represents the amount of manure applied per unit of land and is represented as $x(r)$. The amount of total manure application at distance r is therefore $2\pi r x(r)$.

Manure is assumed to contain nutrients that can be used as a substitute for commercial fertilizer in crop production and these nutrients are represented as vector \mathbf{g} . Because manure can substitute for commercial fertilizer, it is assumed manure has a value equal to the commercial

fertilizer that is not used. That is, the marginal value of a unit of manure is equal to the vector of the price of commercial fertilizer nutrients times the vector of amount of nutrients, $q'g$.

It should be noted that there is some nutrient intensity limit beyond which additional nutrients applied to land are excessive and not taken up by crops. Let this critical value of application intensity be represented by x_1 . Therefore, nutrients applied at an intensity greater than x_1 are not valued as highly as the necessary nutrients and since they are in excess, can lead to the possibility of nutrient runoff and buildup in topsoil. Overall, total benefits to animal producers provided by manure application, either through crop ownership or through agreements with neighboring cropland owners, is represented as $b(x(r))$. Following the stylized facts of Innes, total benefits increase at a constant rate of $q'g$ for all intensities up to the critical value x_1 and thereafter marginal benefits begin to decrease at an increasing rate.

Transportation costs are an important consideration of manure application and are a function of the distance from the production area, $t(r)$. That is, the derivative of the transportation cost function with respect to distance is positive, $t'(r) > 0$. A cost for acquiring the land used for application is added to Innes' original model. This land cost represents either the purchase price for land or the contracted price providing easement to land for manure application. The value of c is assumed to represent an average per unit price of land and therefore total cost for all land used is represented as $\int_0^{\bar{r}} 2\pi r c dr$. The optimization problem of operations maximizing benefits from field application can then be written as

$$\max_{x, \bar{r}} \int_0^{\bar{r}} 2\pi r \cdot [b(x(r)) - t(r)x(r) - c] dr. \quad (1)$$

This optimization is subject to a manure constraint which calls for all manure produced to be applied to fields. This is represented as $\int_0^{\bar{r}} 2\pi r \cdot x(r) dr = \alpha a$. We add a land constraint to

Innes' model to examine the implications for manure application. This constraint is represented as $\int_0^{\bar{r}} 2\pi r dr \leq \bar{L}$, where \bar{L} is the amount of total land available.¹ This constraint is represented as an inequality in order to demonstrate that availability of land may or may not be a binding constraint. The Lagrangean function is therefore

$$L = \int_0^{\bar{r}} 2\pi r \cdot [b(x(r)) - [t(r) + \lambda]x(r) - c - \mu] dr + \lambda \alpha a + \mu \bar{L}, \quad (2)$$

where λ and μ are the shadow prices of manure stock and land respectively. The resulting first order conditions obtained through differentiation are

$$b'(x(r)) = t(r) + \lambda, \quad (3)$$

$$\frac{b(x(\bar{r}))}{x(\bar{r})} = t(\bar{r}) + \lambda + \frac{c + \mu}{x(\bar{r})}. \quad (4)$$

The first condition states that the marginal benefits of manure application should equal the marginal application costs (transportation costs plus the opportunity cost associated with the manure stock). In Innes' original model there are no costs for acquiring land and also no land availability constraint. In the absence of these factors, Innes demonstrates that at the perimeter of land application, \bar{r} , manure intensity is less than or equal to the critical level x_l . That is, manure is spread at agronomic levels or below at the outer edge of land application areas and therefore there is no expected nutrient problems associated with this application. When these land considerations are included, it can be seen, using the relationships of equations (3) and (4) that

$$\frac{b(x(\bar{r}))}{x(\bar{r})} = b'(x(\bar{r})) + \frac{c + \mu}{x(\bar{r})}. \quad (5)$$

¹ Note that this constraint implies that land located closest to the production area is available while the constraint is applied on land further from the production area.

When $c=0$ and $\mu=0$, this represents the case where land is costless and availability is not a binding constraint and the original Innes result is obtained. When c and/or μ are positive, this represents when these land considerations are relevant and demonstrates that at the optimal \bar{r} the marginal benefit from increasing intensity is actually less than the per unit benefit of application. This can be true only when marginal benefits are decreasing and therefore it must be the case that the intensity of spreading is higher than x_l at the perimeter. That is, when there are costs associated with acquiring and holding land, the optimal amount of land used for application decreases.

This result is interesting given the fact that the model also demonstrates that application intensities increase as the distance to the production (or manure storage) area decreases. That is, manure is applied at higher intensities closer to the production area. As in Innes, differentiating equation (3) yields,

$$\frac{\partial x^*(r)}{\partial r} = \frac{t'(r)}{b''(x^*)} < 0,$$

and therefore, not only is application undertaken at levels higher than critical intensity at the perimeter, but these intensities then increase as application is undertaken at distances closer to manure production areas. This result suggests that in lieu of regulations, operations have incentive to apply manure at greater than critical intensity levels over *all* land. In addition, as the cost of acquiring additional land, c , increases, then marginal benefits of application must decrease and therefore intensity increases over less land. High land purchase or rental prices lead to increased manure application intensities.

The next section examines results on current swine waste manure handling practices, land application methods, and land constraints obtained from a survey of Oklahoma hog producers. This examination helps to reveal the circumstances surrounding land and manure transportation

issues in Oklahoma and also helps to determine the types of regulatory policies that would be most appropriate to control runoff pollution.

5. Pilot Survey of Oklahoma Hog Producers

Our pilot survey of Oklahoma producers was sent to an initial sub-sample of 103 Oklahoma producers, whose addresses were obtained from the Oklahoma Department of Agriculture. From this sample, we received useable responses from 25 hog producers. Although this sample is quite small, we are able to generate some tentative conclusions about manure management practices in Oklahoma.

Land Application Practices

Two manure application methods account for the bulk of the land application of manure. Irrigation guns, often mounted on tanker trucks is the most common application method, used by 61 % of respondents and accounting for approximately 52% of the manure applied to land (Tables 1). Pivot irrigation systems fed by irrigation pipe systems are used by 43% of producers and account for approximately 39% of manure application. No producers in our sample use injection methods. Incorporation of effluent into the soil is also uncommon in Oklahoma (Table 1). Approximately 83% of producers never incorporate manure into the soil, accounting for 76% of all manure, whereas 9% incorporate some of their effluent within one day, 17% incorporate some of their effluent within 4 days, and 9% incorporate some effluent within one month.

There is also seasonal variation in effluent application. On average, approximately 28% of effluent is applied during the spring, 53% during the summer, 19% during the fall, and only 2% in winter (Table 2). One interesting question relating to water quality issues is the tradeoff between yield productivity from spring applications and the potential for excess runoff from relatively heavy spring rainfall events.

Ownership, contracting, and markets for manure application

Most respondents own all of the land on which they apply manure. Of the sample of 25, seven respondents either had acquired permanent manure application easements on others' land or had developed long term contracts with other landowners for manure application. On average, these seven owned just over 30% of the land on which they apply manure. One of the producers maintained a ten year contract on 800 acres for which he received \$0.003333 per gallon of effluent, and another producer maintained a 30 year contract on 600 acres for which he pays \$0.004 per gallon. The rest of the contracts are based on a price of zero for the effluent.

Relationships between nutrient content, application practices, and soil tests

An implication of the theory that transportation costs lead to over-application of nutrients near hog barns is that soil nutrient levels ought to be higher near barns than far away from barns. Based on survey responses, we generated t-tests to test whether this is in fact the case. Although our small sample does not provide enough statistical power to develop useful confidence intervals for this question, we present these t-tests in table 9. The point estimates show soil tests for Nitrogen, Phosphorous, and Potassium all tend to be higher in fields nearest to barns than in fields farthest from barns. This result is consistent with the transportation cost hypothesis. However, none of these test statistics are significantly different from zero, probably in part due to our small sample size.

Navin and Innes (cited in Innes) find evidence that the use of manure increases nutrient applications. We can also perform a test of a similar hypothesis, that the number of animal units per acre is positively related to soil nutrient levels. To do so, we generated estimates of the amount of Phosphorous and Nitrogen produced on each farm. The conversions are based on data presented in table 2-2 of the Livestock Waste Facilities Handbook. Then we performed simple

linear regressions to test whether P and N soil tests were higher on farms that produced more P and N, respectively (Tables 10 and 11).

Our results are mixed. Phosphorous soil tests appear to be positively correlated (with high significance) to Phosphorous production levels (Table 10). Nitrogen soil tests, however, are negatively correlated with Nitrogen production in our sample, with a P-value of just over .10. It is worth noting, however, that Nitrogen soil tests are generally considered to be less reliable than Phosphorous soil tests. Further, Nitrogen volatilizes from the soil over time, but Phosphorous is not lost from the soil as rapidly. More importantly, however, are the weaknesses of our data. In this sample we do not have information on the extent of manure application over time on each of these farms, although most of them have been in operation since 1994 (one new producer who had not yet applied manure to his land was omitted from these regressions).

5. Conclusions

The current status of land availability and land access situation needs to be understood in order to create effective manure management policy. If land availability or access constraints contribute to overapplication of manure nutrients, then regulations should probably support inter-regional transportation and neighbor contracting, whereas land requirements found in many state regulations may be of little value. If transportation costs are a primary factor leading to overapplication of manure and nutrients, then policies such as commercial fertilizer taxes, transportation subsidies, and soil-test based restrictions may be useful. This first attempt at collecting information focuses on hog production in Oklahoma. Future analysis will examine production of different animals in different geographic regions to capture the heterogeneity in production systems and geographical considerations such as climate.

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Tables

Table 1: Field application methods: summary of reported percents

	N	Mean	Std Dev	Min	Max
pivot irrigation system	23	38.9	47.1	0	100.0
injection system	23	0.0	0.0	0	0.0
irrigation gun	23	52.4	48.4	0	100.0
other application method	23	0.0	0.0	0	0.0
no incorporation	23	75.5	41.1	0	100.0
incorporation after one day	23	3.0	11.7	0	55.5
incorporation after 4 days	23	8.0	22.3	0	100.0
incorporation after 1 month	23	4.9	16.3	0	62.5

Table 2: Application: average % applied, by season

	N	Mean	Std Dev	Min	Max
% manure applied in Spring	23	27.9	23.1	0	70.0
% manure applied in Summer	22	53.4	29.7	0	100.0
% manure applied in Fall	23	18.8	17.2	0	50.0
% manure applied in Winter	23	2.3	4.5	0	17.0

Table 3: t-test: soil tests near vs. far from barn (DF=14 for all)

Difference	Mean	t Value	Pr > t
N (near) – N (far)	2.2667	0.72	0.4821
P (near) – P (far)	0.8667	0.08	0.9402
K (near) – K (far)	7.3667	0.27	0.7922

Table 4: Regression; Dependent Variable: Soil test P(lbs/acre), Nearest barn

R-Square = 0.3237	Estimate	Std. Err.	t Value	Pr > t
Intercept	28.99	3.876	7.48	<.0001
manure P produced per acre	0.178	0.078	2.29	0.0424

Table 5: Regression; Dependent variable: Soil test N (lbs/acre), Nearest barn

R-Square=0.2250	Estimate	Std. Err.	t Value	Pr > t
Intercept	29.95939	4.58956	6.53	<.0001
manure N produced per acre	-0.15190	0.08501	-1.79	0.1015

Table 6: Dependent Variable: P test on nearest field over P test on farthest field

R-Squared=0.6184	Estimate	Std. Err.	t Value	Pr > t
Variable				
Intercept	1.3764	0.4648	2.96	0.0143
(farthest distance/shortest distance) to field	-0.0041	0.0071	-0.58	0.5759
manure P produced per acre	0.0288	0.0076	3.80	0.0035