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Pressures and Preferences Affecting Willingness to Apply Beef Manure on Crops in the Colorado High Plains

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Little is known about producers' willingness to use manure. Past studies have focused on substitutability for fertilizers. We surveyed crop producers in a cattle-dense region of the Colorado Plains about whether and why they apply manure, focusing on how pressures (like owning cattle) or preferences (pro and con) affect their adoption. Using logistic regression, findings show that pressure and preference (PS/PF) significantly affect adoption. A producer with high PS/PF was 10 times more likely to use manure than one with low PS/PF. Policy and decision makers can use such findings to inform education and policy aimed at increasing the land application of manure.

Key words: cattle, economic benefits, economic costs, management, manure application

Introduction

Nutrient management on large animal feeding operations (AFOs) is widely researched in economics and other literature (e.g., Dennehy et al., 1998; Letson and Gollehon, 1996), yet nutrient pollution remains the leading cause of water quality impairment in lakes, estuaries, and rivers [U.S. Environmental Protection Agency (USEPA), 2002]. Furthermore, the highest concentrations of nitrogen and phosphorus can be traced to fertilizers and manure applied to crops (Copeland and Zinn, 1998; Gollehon et al., 2001).

In a recent U.S. Department of Agriculture (USDA) report examining manure management, Ribaudo et al. (2003) found that over three-fourths of large hog and dairy operations in the United States exceed agronomic application rates, and up to one-half do not have enough acres to spread the manure they produce. The purpose of the Ribaudo et al. report was to estimate farmers' costs to meet nutrient management standards on concentrated animal feeding operations (CAFOs) as promulgated by the USEPA. However, because they had no information about farmers' willingness to apply manure, the authors note that a confident estimate proved somewhat elusive (p. 85). Consequently, their recourse was to estimate costs as if 10%, 20%, 30%, ..., 100% of farmers were willing to apply manure on their available cropland—and their results were therefore sensitive to these application assumptions. For example, the cost in a regional model for a nitrogen standard in the Chesapeake Bay increased from $54.84 million if 100% of available acres receive manure to $73.11 million for 20%. In their

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farm-level analysis, costs on an operation with fewer than 1,000 animal units in the West were at least one-sixth as high when 80% of available acreage received manure compared to 10%. Our focus is to empirically examine willingness to apply manure by addressing the extent to which producers treat manure as a nutrient substitute.

Little is known about willingness to apply manure because previous analyses of manure application have not assessed adoption behavior (e.g., Ribaudo et al., 2003, as discussed above). Instead, studies to date have emphasized the relative prices of manure and inorganic fertilizers. If used as a basis for understanding the manure adoption decision, analyses of this kind implicitly assume that producers will apply manure if it is cost-competitive as a factor substitute for inorganic fertilizer or as a way to cheaply dispose of a waste by-product (Council on Agricultural Science and Technology, 1996; Innes, 2000; Lazarus and Koehler, 2002; Fleming, Babcock, and Wang, 1998; Freeze et al., 1993; Freeze and Sommerfeldt, 1985; Schnitkey and Miranda, 1993; USDA/Animal and Plant Health Inspection Service, 1995). However, this assumption may not be borne out in producers' behavior. As reported by Ribaudo et al. (2003), meeting nitrogen regulation standards in some cases would actually reduce costs, supporting the notion that factors other than nutrient and hauling costs matter to producers. This perspective demonstrates the need for a positive study of manure adoption, analogous to those typically conducted in the agricultural technology adoption literature (e.g., Amponsah, 1995; Buttel, Larson, and Gillespie, 1990; Putler and Zilberman, 1988).

This analysis reports on an empirical study about the use of manure by crop producers in a cattle-feeding-intensive area of Colorado's high plains. Our goal is to shed light on what kinds of factors affect farmers' willingness to apply manure. A simple theoretical model is constructed, placing the manure use decision in the context of pressure variables [supply (push) and demand (pull) for manure from the farmer] and preference variables (producers' subjective beliefs about the benefits and problems of manure use). Survey data are then presented, and analyzed using logistic regression, to examine the impact of pressure and preferences on the manure adoption decision.

This research contributes to the literature in three ways. The current study is the first published positive study of the manure adoption decision. Specifically, we empirically examine "willingness to apply," which should provide a first step toward reducing the uncertainty involved in economic policy analyses of the manure management problem. According to Ribaudo et al. (2003, p. 85), this type of study would "identify areas for education and extension that might reduce cropland operators' reluctance" to use manure as a primary source of nutrients. Second, our focus on pressure and preference variables takes the current study beyond implicitly treating manure as though crop producers view it only as a nutrient substitute with some special transportation and application costs. Finally, manure management is examined here in the context of beef production, an important source of problems in most of the western half of the United States, which has received relatively little treatment in the economic manure literature.

Case Study Region

The area chosen for study, a portion of Weld County along the South Platte River Basin in Colorado, has one of the largest and densest populations of cattle and feedlots in the United States, and includes several of the world's largest feedlots, with some holding more than 100,000 cattle at any point in time. Not surprisingly, this area supports large

volumes of crop production—not only animal feed crops such as corn, alfalfa, and grasses, but also vegetable crops such as potatoes, onions, sugar beets, and grain crops including wheat and barley. Weld County is consistently among the top five U.S. agricultural sales counties. The proximity of intensive animal and crop production, along with a substantial history of agricultural manure usage, provides an excellent opportunity for studying adoption of manure use in a location in which overapplication is a common occurrence, and in which expanded adoption of manure use could help mitigate potential pollution problems. Over three-quarters of the mass of waste produced in Weld County must be transported away from where it was produced (Dennehy et al., 1998). Furthermore, groundwater nitrate-nitrogen concentrations have routinely been measured in excess of the recommended maximum level of 10 ppm in the Platte Valley (Bishop, 1994; Dennehy et al., 1998; Wylie et al., 1994).

To define a population of crop producers to survey within this area, we started with an AFO-dense area of Colorado previously examined in a groundwater-nitrate management study completed by Hall in 1996. We then expanded the boundaries of Hall's study area by approximately 10 miles on each side so as to define a region that would include all crop producers near the feedlot-intensive areas who would likely use manure from one or more of the feedlots in the area. We were unable to formally investigate, prior to the study, the distances manure is actually transported within this region. Thus it is possible (though unlikely) some crop producers located farther away might also use transported manure. However, consultation with local informants suggested that transportation of manure beyond even a five- to six-mile distance was quite unusual, consistent with economic literature (Schnitkey and Miranda, 1993). In any event, our goal was to define a population of crop producers in an area in which manure use is reasonably common, and the 10-mile radius does capture such a population.

Modeling Manure Adoption

As a basis for identifying variables that affect the decision to apply manure, we begin by drawing upon information from the general approach adopted in previous studies about manure use. Most studies investigating manure application implicitly assume that derived manure demand (MA) is a function of own price (w_m), including adjustments so that costs are in equivalent terms to inorganic fertilizer, the price of inorganic substitute fertilizers (w_f), and output price (PO):

$$MA = f(w_m, w_f, PO). \tag{1}$$

The focus of these earlier studies has been to determine the substitutability of manure and fertilizer. For example, Lazarus and Koehler (2002) examine the economics of hauling and the implications of applications based on N compared to P, as do Fleming, Babcock, and Wang (1998). Lazarus and Koehler propose three components in their feasibility study: the cost of owning and operating manure application equipment, the time required to apply manure, and the fertilizer replacement value of manure. Each of these variables essentially serves to adjust the price of manure (w_m) to make it comparable to the price of commercial inorganic fertilizers. Schnitkey and Miranda (1993) postulate that profit maximizers consider distance of the crop field from the manure source, as well as the profitability of livestock, crop price, price of commercial

fertilizer, manure application cost, manure production level, yield response to nitrogen, and phosphorus carryover. In addition to the variables above, Schnitkey and Miranda include manure production from elsewhere in the operation, since it reduces the real price of manure-based nutrients through savings in the livestock enterprise. Hoag and Roka (1995) found that manure value was also a function of storage and treatment cost, which varies significantly from one location to another (e.g., weather, soil type). Innes (2000) describes the incentives for overapplication in terms of distance, nutrient content in manure, and monetary benefit of manure nutrients.

Consider the substitutability of manure for fertilizer, which is based on relative prices. The cost of manure applied (w_m) must be adjusted into commensurate units with inorganic fertilizer before comparisons can be made. Commonly, w_m includes transportation, storage, and the amount of nutrients contained in the manure. However, based on the finding of Ribaudo et al. (2003) that farmers do not adopt when it is profitable, there may be more variables to consider when making comparisons of w_m with the price of inorganic fertilizers. Specifically:

$$w_m = g(HD, HC, NC, PP, AEC, TC, AC: PS, PF), \tag{2}$$

where HD is hauling distance, HC is hauling cost, NC is nutrient content, PP is price paid for manure, AEC is amortized equipment cost, TC is treatment cost, and AC is application cost. For simplicity, we begin by looking at whether price is also conditional on pressure variables (PS) and preference variables (PF) that have not been measured.

To estimate whether pressure and preference variables affect adoption, compared to traditional variables (TV), we apply the concepts of the Frisch-Waugh-Lovell theorem (Davidson and MacKinnon, 1993), which states that a linear or separable model of the form

$$w_m = f_1(TV)\hat{\beta}_1 + f_2(PS, PF)\hat{\beta}_2 \tag{3}$$

can be rewritten as

$$w_m - f_1(TV)\hat{\beta}_1 = \hat{f}_2(PS, PF)\hat{\beta}_2 \tag{4}$$

without changing the coefficient estimates on $\hat{\beta}_2$. (The coefficients in the $\hat{\beta}_1$ and $\hat{\beta}_2$ vectors are assumed conformable with the variables in TV, and PS plus PF.) The dependent variable is now the residuals of a regression of w_m on TV. From equation (4), $\hat{f}_2(\cdot)$ refers to the residuals of a regression of PS and PF against TV, thus using the variation in PF and PS which is independent of TV. If TV is independent of PS and PF, which appears likely in this case, the original values of PS and PF can be used. Then we can test whether the effects of PS and/or PF on adoption are significantly different from zero.

This result is important, since we did not have information about the traditional variables. It would be very difficult to apply a consistent approach to measuring traditional variables by survey. Moreover, the dependent variable in equation (4) is a latent variable because we do not have a consistent series on TV. Therefore, a logit model is estimated (shown later) where adoption is based only on PS and PF, implying that the influence of the unobserved latent variable (TV) is already included in the left-hand side of equation (4) with the price variable for manure. That is, if a producer adopts, given

some level of *PS* and *PF*, *TV* is either compounding the adoption decision, or subtracting from that producer's desire to adopt, but not enough to overcome the positive influence of *PS* and *PF*. And we have proven, given our assumptions, that *TV* is not sufficient to predict adoption.

The Survey

An attempt was made to survey the entire population of cropland operators in the study area described above. To do so, an initial list was assembled using aerial photograph records from the local Farm Service Agency (FSA) to identify all fields, and thus all persons within the area who had farmed land in conjunction with a federal crop program in the last several years. This process identified 1,170 individuals. Following traditional procedures suggested by Dillman (1978), an initial questionnaire was mailed to each of these 1,170 persons in November 1998, and the initial mailing of the questionnaire was followed by a postcard reminder after two weeks. After another three weeks, a second copy of the questionnaire was sent to all nonrespondents. A fourth and final mailing was made to a small number of persons whose addresses were corrected based on mailings returned as undeliverable. A total of 273 surveys were completed and returned. Using information obtained after the survey, it was determined that only 693 persons of the original 1,170 were actually current crop producers within the area.[1] Thus, the 273 completed surveys correspond to a response rate of 273/693, or 39% of the population of known crop producers.

Description of the Questionnaire

The questionnaire contained five sections: (*a*) farm characteristics; (*b*) manure usage, including questions about willingness to buy/sell manure; (*c*) views about benefits and problems of manure use; (*d*) general farming practices questions; and (*e*) demographic information. Farm and ranch characteristics included acreages for various crops, number and type of livestock, and what portion of the operation was rented or leased. Demographic information included number of years in agriculture, level of education, approximate annual gross revenue from farming or ranching, and whether the respondent worked at another job outside the farm or ranch.

The main body of the questionnaire posed three sets of questions. In the first set, the respondent was asked about the operation of two "typical" fields, one of which had manure applied to it in the preceding season, and one of which did not. This was the source of the dependent variable used in the current study (manure applied to any field versus none). Respondents who did answer about a manured field were "manure adopters" for the purpose of this study, while those who had no manured field were instructed to leave that section blank, and constitute the nonadopters in this study.

While various field-specific questions were asked, for current purposes, the following section, which solicited respondents' views ("preferences") about the benefits and problems of manure use, is of most interest. The questionnaire presented a list of potential

[1] A total of 84 questionnaires were returned that indicated the respondent had died or was no longer farming in the area. In addition, after our survey was complete, personnel at the local office of the National Agricultural Statistics Service examined our initial list and reported that 393 persons on the list did not appear as crop producers in the *1997 Census of Agriculture*.

problems and benefits associated with manure application, drawn from those commonly cited in the literature and from those mentioned by local producers in informal interviews. Respondents were asked to rate each problem/benefit item on a five-point Likert scale, where 5 = a problem or benefit that is "real and significant," and 1 = a problem or benefit that "does not matter or does not really happen." The final section of the questionnaire focused on farming practices in general, as well as the issue of groundwater nitrates.

Description of Survey Respondents and Their Operations

Respondents to the survey represented a wide range of operations, both in size and type. Average total size of the sample operations was 502 acres, somewhat smaller than the county-wide average of 647 acres, as reported by the *1997 Census of Agriculture* (USDA, 1999). Fifty-three percent of the survey respondents grossed under $100,000 per year, compared to about 76% in the county as a whole. Most farms were oriented toward either animal or feed production. Thirty-eight percent of the respondents reported some kind of animal production, with 88% of the animal producers being cattle producers.

Corn was the predominant crop, with 35% of respondents citing it as their largest crop acreage, followed by pasture and alfalfa (about 16% each), other grass or hay (8%), and wheat (8%). Fifty-six percent of respondents were manure users—i.e., they reported having applied it to at least one of their fields during the preceding growing season. About half (47%) of users applied manure from their own livestock, 29% received manure free or received credit for hauling it away from a feedlot, and only 14% actually purchased all the manure they used. Approximately 10% supplemented their own livestock's manure with manure obtained from someone else, and about half of the manure users hired someone else to haul and spread it.

Pressure and Preference Variables

To operationalize the preceding model, we used two pressure variables, livestock owned and acres of corn, and two preference variables, the perceived benefits and problems associated with manure use. Number of livestock owned represents a supply-push pressure that increases the incentive to use manure by increasing the need to dispose of waste. That is, all else equal, a producer with more livestock will be less indifferent between manure and inorganic substitutes than an individual with fewer livestock. We measured this pressure with average number of head of cattle in the farm operation in the preceding season, and ignored other species, since cattle were overwhelmingly the most common livestock species in the study area.

The second pressure variable was acres of corn grown during the preceding season. The amount of acreage over which a producer can effectively apply manure is a demand-pull pressure. Moreover, the presence of more acres of corn crop in the area increases the benefits of spending time to reduce unit cost of nutrients, and spreads fixed costs of specialized equipment and management needed for manure application over more land. Although crop species other than corn might benefit from manure application, and so constitute a source of demand for manure, a focus on corn is justified for purposes here because it constitutes a large part of total crop acreage in the locale studied, and because it has large nitrogen requirements, making it an attractive choice for manure

application. Further, a preliminary exploratory data analysis indicated that corn acreage had a stronger relationship to manure use than did total acreage or acreage of any single other crop. (For a similar finding, see Schuck and Birchall, 2001.)

The two preference variables, *Problems* and *Benefits*, involve farmers' subjective perceptions concerning the negative and positive effects of manure use, which are difficult to quantify in strictly economic terms. Above and beyond the direct economic pressures or inducements to use manure, we hypothesized that farmers' "tastes" for manure use would affect their manure application decision. This subjective angle differs from the farmer characteristics included in many adoption studies, but is quite consistent with conventional economic theory about the importance of irreducible personal preferences with regard to any economic decision. While we first considered inclusion of farmer characteristics more typically used in adoption studies—such as age, years in farming, education, and so forth—exploratory analyses indicated that such factors had little association with manure use adoption. Thus, the preference or taste factors are the only farmer characteristics included in our model.

To measure these subjective preferences, we constructed attitude indices from a series of Likert statements about potential benefits and problems of manure use, as described above in the discussion of the questionnaire. The left-hand columns of table 1 display a brief description and summary statistics for each of these manure preference items. The most important benefits, as perceived by our respondents, were "improves soil properties" and "source of organic matter," which were indications that manure and conventional fertilizers may not simply be factor substitutes in the eyes of crop producers. The most important problems identified were "causes weeds" and "soil compaction." (Manure application in the study area typically is done by driving a 20-ton spreader truck through the field, which can increase compaction.) Again, these are properties characterizing manure differently than simply as a substitute for conventional fertilizer. As observed from table 1, almost all of the *Benefits* items had higher average ratings than did any of the *Problems* items. If benefits and problems items are regarded to be of comparable difficulty, this would suggest positive preferences about manure use were stronger than negative ones in this sample. On the other hand, it may be that benefits and problems items are not of comparable difficulty, in which case these differences in response need not reflect greater salience for positive than negative views.

To construct the manure attitude indices, we began with a principal components analysis of all the benefits and problems items listed in table 1 in order to determine whether internally consistent, unidimensional attitude indexes could be formed from the data. Three distinct, orthogonal components emerged from this analysis of the manure attitude items. (This and other analyses reported here were performed with SPSS v. 11.0.1 library programs.) As the component loadings in the three right-hand columns of table 1 show, items referring to "agronomic problems" loaded heaviest on component I (23% of total variance). A second set of items, labeled here as "agronomic benefits," pertain to aspects of manure perceived as beneficial to crop production. These items listed under *Benefits* in table 1 loaded on component II (22% of total variance). Finally, three items referring to non-agronomic problems (neighbors, regulations, and water pollution) loaded on component III (14% of total variance), but are not considered here, and are omitted from table 1. No other component had an eigenvalue greater than 1.0, and the scree curve flattened sharply after the third component. No cross-loadings over 0.4 occurred. Following conventional guidelines for attitude index construction (e.g.,

Table 1. Descriptive Statistics and Principal Component Loadings for Manure Preferences (*Benefits* and *Problems*) Items (N = 220)

Manure Preferences[a]	Mean	Std. Dev.	Loading for Component:[b] I	II	III
Benefits:					
Improves soil properties	4.33	1.06	0.031	0.884	-0.167
Source of organic matter	4.26	1.12	0.037	0.877	-0.164
Increases yield	4.08	1.21	-0.012	0.855	-0.104
Inexpensive fertilizer	3.78	1.35	-0.047	0.739	0.093
Dispose of livestock waste	3.50	1.55	-0.303	0.630	0.110
Reduce wind erosion	3.20	1.41	-0.071	0.596	0.190
Problems:					
Causes weeds	3.25	1.32	0.717	-0.108	-0.140
Soil compaction	3.12	1.42	0.700	0.026	0.170
Inconvenient to apply	2.92	1.27	0.624	-0.019	0.230
Regulatory concerns	2.82	1.50	0.258	0.168	0.777
Unpredictable nutrients	2.73	1.37	0.652	-0.032	0.279
Additional tillage required	2.69	1.20	0.751	-0.032	0.244
Uneven spreading	2.66	1.25	0.708	-0.003	0.251
Salt damage	2.65	1.25	0.649	-0.142	0.227
Water pollution	2.45	1.37	0.339	-0.014	0.791
Relationship with neighbors	2.20	1.33	0.334	-0.111	0.696
Lower crop yield	2.01	1.28	0.510	-0.105	0.359

[a] Item scoring on a five-point Likert scale, where 5 = "real and significant" benefit/problem, and 1 = "doesn't really matter or doesn't really happen."
[b] Loadings on each component extracted from a principal components analysis with varimax rotation.

McIver and Carmines, 1981), this component structure would support the legitimacy of combining items into separate attitude indices.

In the current analysis, interest was focused on the items loading on components I and II. Each respondent was given a "Manure Problems" index score equal to the mean of her/his score on the problems items that loaded on component I, and a similar "Manure Benefits" index score based on mean scores on the benefits items loading on component II. (Respondents who failed to respond to a few items were assigned their mean on the nonmissing items.) These indices were scaled so that higher scores indicate, respectively, a stronger perception of the agricultural problems and benefits of manure use. Both indices met conventional criteria for internal consistency (Cronbach's alpha = 0.86 for the six benefits items, and alpha = 0.85 for the eight problems items). These two additive Likert indices, then, were used as measures of farmer subjective preferences concerning manure use. For the current purpose, the items loading on component III were omitted from consideration.

An interesting feature of these two indices is that they were almost completely uncorrelated (r = -0.093). This finding suggests farmers' attitudes toward manure use were not simply a collection of "manure is good/bad" prejudices, nor did benefits and problems simply represent opposite poles of such a continuum. Instead, farmers' responses displayed a more sophisticated recognition of manure as a mixed blessing; i.e., the lack of correlation indicates that a given respondent might believe strongly in both

Table 2. Correlations of Benefits and Problems Indices with Producer and Farm Characteristics

Variable	Manure Benefits Index	Manure Problems Index
Total crop acreage, current year	0.072	0.034
Corn acreage	0.080	-0.018
Wheat acreage	0.025	0.089
Average number of cattle, current year	-0.083	0.124*
Gross farm sales, preceding year	0.075	0.061
Years of experience in farming/ranching	-0.095	0.136*
Education level	0.061	0.008

Note: An asterisk (*) denotes $p < 0.05$.

the benefits and problems of manure use. Another finding of note was that the manure preference indices had only weak relationships with producer and farm characteristics, as seen in table 2, which shows the correlation of the benefits and problems indices with several farm and operator characteristics. All correlations of the benefits and problems indices with total acreage, corn acreage, wheat acreage, number of cattle, and gross sales were below 0.13 in absolute value, with the strongest correlation indicating a modest positive relationship between number of cattle and the problems index. Neither did characteristics of the operators, including years of farming/ranching experience and educational level, correlate strongly with manure attitudes, with the strongest relationship being $r = +0.136$ between years of experience and the problems index.

The Statistical Model

In the current analysis, manure use is treated as a dichotomy. The dependent variable was whether the respondent was a manure user, operationally defined as having applied manure to at least one field during the preceding year. This adoption outcome was modeled using logistic regression, with the predictors being the pressure variables (number of acres of corn and number of cattle), and the preference variables (the perceived benefits index, and the perceived problems index). We posited that the pressure variables pushing the producers away from indifference about manure would have a positive effect, but this effect would decline with increasing pressure. On this basis, a natural specification would have involved using the logarithms of the number of cattle and of corn acreage rather than the use of these variables in their raw form. However, some respondents had either no cattle or no corn acreage, leading to unidentified terms such as ln(0). We initially attempted to manage this problem by adding a small constant to the cattle and corn variables. Unfortunately, coefficient estimates were found to differ substantially depending on what constant (0.5, 1.0, 5.0, 10) was chosen. To address this problem, we have used a square root term to specify a function that is concave downward. Thus, the specification estimated here was as follows:[2]

[2] In addition to this relatively simple specification, we also considered models containing cross-product terms such as *Benefits* × *Problems*, *Corn* × *Cattle*, *Corn* × *Benefits*, etc. Because of our limited analytic goal—i.e., to show that variables beyond those indicated in previously published literature were relevant to the manure use decision—we decided that a more complex model was unnecessary at this point. Moreover, our specification fit as well or better than any other we tried.

$$\ln\left(\frac{P}{1-P}\right) = b_0 + b_1C + b_2C^{1/2} + b_3T + b_4T^{1/2} + b_5B + b_6M, \tag{5}$$

where P represents the probability that a farmer reported having applied manure to at least one field, C is the number of acres of corn grown in the previous year, T is the average number of cattle the respondent owned in the previous season, B is the score on the manure benefits attitude index, and M is the score on the problems index.

Before proceeding, we emphasize an important limitation concerning the interpretation of model fit here, namely that the cross-sectional design of the current study cannot establish a direction of causality. For example, it is possible that preference for using manure might influence the decision to own cattle, but this is likely the exception rather than the rule. More importantly, expressed beliefs about the benefits and problems of manure use might reflect a farmer's post hoc rationalization of behavior, rather than being the causes of that behavior. Or they might reflect beliefs drawn from past experience with manure use, which might also affect future choices. Consequently—although for convenience, we speak below in terms of coefficient estimates for the model as "effects" on manure use—they can only fully be defended as indications of associations with manure use.

Results

Basic Logistic Regression Results

Descriptive statistics for model variables are reported in table 3, with coefficient estimates for the fitted regression model given in table 4. Overall, the model appears to fit well, with a p-value under 0.0005 for the overall likelihood-ratio test. All variables also appear to be significant with at least a p-value under 0.03.

The results in table 4 reflect the omission of one case, based on an analysis of influential cases. Standardized DFBETAS, which give the change in coefficient estimates that would occur if a case were omitted, were calculated for all coefficients (Long, 1997). Except for that one case, all standardized DFBETAS were less than 1.0 for all covariates for all cases, and almost all were less than 0.3. Accordingly, the one influential case (a large cattle producer with a standardized DFBETA of 3.2 for the linear cattle term) was dropped prior to the results reported in table 4. After dropping that case, the reestimation occasioned no influential cases by the DFBETA criterion.

The marginal effects implied by the coefficients in table 4 are all in the anticipated direction. Although the linear effects of both cattle numbers and corn acreage on the logit of manure use are negative, which might seem anomalous for these two pressure variables, those effects are counterbalanced by the positive effects of the square root term for each variable. For example, the derivative of the logit of manure use with respect to corn acreage is $[-0.435 + 1.74(0.5)C^{-1/2}]$, where C is corn acreage in 100s, which translates to a positive marginal effect whenever corn acreage is below about 400 acres. Approximately 20% of producers in our sample have over 400 acres of corn, where the marginal impact becomes negative. This is likely a scale issue since manure is bulky and difficult to apply. For the more typical producer, such as one at the mean (159) corn acreage, the derivative of the logit of manure use with respect to corn acreage would be positive (0.238). A 100-acre increase in corn production for the mean producer size would

Table 3. Descriptive Statistics for Variables Used in Model

Variable	Mean	Standard Deviation	Range
Corn Acreage	159	314	0 to 2,400
Number of Cattle	79.2	382.7	0 to 5,000
Manure Benefits Index	3.88	0.980	1.0 to 5.0
Manure Problems Index	2.78	0.923	1.0 to 5.0
Manure Use (1 = yes, 0 = no)	0.556	0.498	N/A

Table 4. Logistic Regression of Manure Use on Corn Acreage, Number of Cattle, Perceived Benefits, and Perceived Problems (N = 238)

Variable	b	Standard Error	p-Value [a]
Constant	-3.140	0.979	0.001
Corn Acreage (100s)	-0.435	0.137	0.002
(*Corn Acreage*)$^{1/2}$ (100s)	1.740	0.405	< 0.0005
Number of Cattle (100s)	-0.453	0.108	0.03
(*Number of Cattle*)$^{1/2}$ (100s)	2.180	0.615	< 0.0005
Manure Benefits Index	0.921	0.189	< 0.0005
Manure Problems Index	-0.474	0.192	0.01
Likelihood Ratio χ^2 (df = 6) for entire model	84.2		< 0.0005
McFadden Pseudo-R^2	0.260		

[a] The p-values are based on Wald tests.

increase the odds of manure use by a factor of 1.20. Similarly, the marginal effect of increasing numbers of cattle on the logit of manure use would be $[-0.453 + 2.181(0.5)T^{-1/2}]$, where T is number of cattle in 100s. The marginal effect of cattle would be positive at values less than about 580 head (approximately the 90th percentile). Again, computing the odds ratio at the mean level of production (79 head of cattle) to provide a more intuitive description of this effect, an increase of 100 cattle would be expected to multiply the odds of manure use by 1.57.

Looking now at the effects of the attitude variables (table 4), which are easier to interpret because of their linearity, a 1.0 unit increase in perception of manure benefits (approximately one standard deviation) is predicted to increase the logit of manure use by 0.921, corresponding to an odds ratio of 2.5. Conversely, a 1.0 change in the manure problems index (also about one standard deviation) is predicted to change the logit of manure use by -0.474, corresponding to a factor change in odds of 0.622. Thus, all the pressure and preference variables have effects that are substantial and are in the theoretically anticipated directions.

Predicted Probabilities of Manure Use

Given the logistic form of the specification here, the predicted *probability* (as opposed to the logit) of manure use varies nonlinearly with the pressure and preference variables, as do the marginal effects on the probability of manure use associated with the

Table 5. Predicted Probability of Manure Use Under Various Pressure and Preference Scenarios

	Pressure Variables Combination			
Preference Variables Combination	[1] High Corn/ High Cattle	[2] No Corn/ High Cattle	[3] High Corn/ No Cattle	[4] No Corn/ No Cattle
[1] High Benefits/Low Problems	0.985	0.898	0.920	0.612
[2] High Benefits/High Problems	0.964	0.786	0.829	0.398
[3] Low Benefits/Low Problems	0.913	0.590	0.655	0.206
[4] Low Benefits/High Problems	0.815	0.376	0.443	0.098
[5] Low vs. High Benefits Effect [a]	0.110	0.358	0.325	0.353
[6] Low vs. High Problems Effect [b]	0.059	0.163	0.152	0.161

[a] The entries in row 5 are the means, within column, of the difference in predicted probability of row 1 vs. row 3, and row 2 vs. row 4. This gives an indication of the typical increase in predicted probability associated with the move from low benefits to high benefits, other things equal.

[b] The figures in row 6 give the analogous computation for a move from high problems to low problems.

pressure and preference variables. Therefore, two other presentations are offered to display the results from the model fitted here. First, table 5 shows the estimated probability of manure use for several different typified pressure and preference scenarios. Second, figures 1 through 4 show how the marginal effects of the independent variables on the probability of manure use vary across their ranges, again using a set of archetypal scenarios.

The row and column descriptors of table 5 define combinations of pressure and preference situations that characterize various kinds of farm and ranch operators and their operations. These combinations are defined so as to correspond to situations that vary from most favorable toward manure use to least favorable. For example, the upper left cell of table 5 would be the most favorable scenario, corresponding to a farm/ranch operator who has a "high" number of cattle (pressure), a "high" corn acreage (pressure), who is "high" in benefits beliefs (preference), and who is "low" on problems beliefs (preference). High values of the corn and cattle variables were chosen based on the actual distribution in the sample, with "high" being approximately the 75th percentile for persons who had any corn or cattle (300 acres and 150 head, respectively). For the benefits and problems indices, we defined "high" and "low" as one standard deviation above or below the mean (index scores of 4.9 and 2.9 for benefits, and 3.7 and 1.9 for problems). The least favorable situation appears in the cell representing the convergence of row 4 and column 4 in table 5, referring to a hypothetical (but realistic) operator who has no corn and no cattle, is low in benefits beliefs, and is high in problems beliefs.

Note first, then, as would be expected, the highest predicted probability (0.985) of manure use occurs for the archetypal individual who has a substantial number of cattle and a large corn acreage, and whose perception of manure's benefits is high and perception of its problems is low. The lowest predicted probability of use (0.098) occurs for the person with no cattle or corn, and who perceived manure's problems as large and its benefits as small. Moving down the columns means moving toward hypothetical individuals whose manure preferences (benefits/problems) should be less favorable to manure use, and the predicted probability of manure as expected, falls.

The results reported in table 5 indicate that the preference variables have their weakest predicted effects when pressure is highest, which is consistent with economic theory of diminishing returns. In the high pressure situation of the first column (high corn/high cattle), moving down the column from high benefits/low problems (first row) to low benefits/high problems (fourth row) decreases the predicted probability of use by only about 0.17, while in the low pressure situation (the no corn/no cattle column on the far right), the same change in preferences down the column decreases predicted probability of use by about 0.51. The analogous drops in predicted probability for the high corn/no cattle and no corn/high cattle scenarios in the middle columns are 0.52 and 0.48.

Just as the effects of changes in preference are smallest when the amount of pressure is large, changes in the pressure variables have the least effect when preferences are most strongly favorable to manure use. In the strong preference (high benefits/low problems) scenario of the first row, the effect of decreases in pressure on predicted probability is relatively small (a decrease of 0.37 comparing the fourth to the first column). By contrast, the largest effects of pressure changes occur in the low preference situations of rows 3 and 4, with low benefits/low problems having a 0.71 probability decrease across the row, and the low benefits/high problems row showing a 0.72 decrease.

Another useful comparison involves examining the relative sizes of the effects of benefits attitudes versus problems attitudes. Although it is arguable whether these share exactly the same metric, the similar size of their standard deviations makes comparisons of their effects meaningful if not strictly commensurable. This caveat being acknowledged, looking back at the coefficients in table 4 would indicate that the additive effect on the logit of manure use of a one unit change in the benefits index was about twice as large in absolute terms (0.921 versus 0.474) as the effect associated with a comparable change in the problems index. Examined on the odds ratio scale, the multiplicative effect of a unit positive change in benefits (2.51 odds ratio) is about 1.5 times as large as the effect of a unit negative change in benefits (1.61). Both of these comparisons suggest that the benefits aspects of preferences are more consequential than the problems dimension.

A similar conclusion about benefits versus problems beliefs can be extracted by comparing predicted probabilities. In table 5, within-column comparisons of row 1 versus row 3, and row 2 versus row 4, show the difference in predicted probabilities of a change from high to low benefits beliefs. The average of these comparisons, within column, is shown in row 5 of table 5. Similarly, comparisons of row 1 versus row 2, and row 3 versus row 4, indicate the difference in probabilities from just the difference in high to low problems perceptions, a comparison summarized in the last row of table 5. Comparing the benefits effects versus the problems effects as shown in these rows indicates that the effect of benefits is substantially larger across all the corn/cattle scenarios, about twice as large as the effects of problems. Regardless of the pressure situation, benefits beliefs are predicted to affect manure use more strongly than problems beliefs.

A Graphical Analysis of Marginal Effects

As a final and more detailed way to illustrate what is implied by the model reported in table 4, we now offer a series of graphical figures showing the marginal effects of changes in the independent variables on the probability of manure use. This was done by taking the derivative of each independent variable with respect to the probability of

Table 6. Expressions for Derivative of Probability of Manure Use, with Respect to Each Variable

Variable	Derivative [a]
Corn Acreage (C)	$(-0.435 + 1.743(0.5)C^{-½})[P(1-P)]$
Number of Cattle (T)	$(-0.453 + 2.181(0.5)T^{-½})[P(1-P)]$
Manure Benefits Index (B)	$0.921P(1-P)$
Manure Problems Index (M)	$-0.474P(1-P)$

[a] $P = \frac{\exp(L)}{1+\exp(L)}$, where $L = [-3.138 - 0.435C + 1.743C^{½} - 0.453T + 2.181T^{½} + 0.921B - 0.474M]$

manure use and graphing them across the range of each independent variable. For a logistic model, the derivative function is written as:

$$\frac{\partial P}{\partial \mathbf{X}_i} = \beta'(\mathbf{X}_i)P(1-P), \tag{6}$$

where $\beta'(\mathbf{X}_i)$ is the derivative of $\ln[P/(1-P)]$, the logit with respect to $\mathbf{X}_i$, and P is the predicted probability of a positive response at some stipulated vector of values for all the $\mathbf{X}_i$. The specific derivatives for the explanatory variable in this study are presented in table 6.

Note that these derivatives require choosing a set of values for the $\mathbf{X}_i$, since P is a function of all the $\mathbf{X}_i$. Some investigators examine the derivatives in logistic regression models with all the $\mathbf{X}_i$ set to their mean values. While this approach has the virtue of giving a simple overall sense of the marginal effect of the various covariates, the vector of the means is often an unrealistic point in the covariate space, to which the situation of no real person in the sample need correspond.

As an alternative, we have selected archetypal situations, similar to those in table 5, to define the vector of $\mathbf{X}_i$ values at which the derivatives are evaluated. For each variable, we chose four archetypes, including (*a*) two extreme archetypes, one very favorable to manure use and the other quite unfavorable; and (*b*) two moderate archetypes, with variables set at values that are moderately favorable to manure use. Then, within each archetype, figures 1–4 display how the marginal effect of each variable on the probability of manure use varies as that variable moves across its own range. For defining the archetypes, we have used the same scores as in table 5 to define high and low values on the benefits (4.9 and 2.9) and problems (3.7 and 1.9) scales, and the same values to define the high values of corn (300) and cattle (150), but instead have used 1 rather than 0 to define low values of corn and cattle, since their derivatives are undefined at 0.

We begin with figure 1 by examining the marginal effects of benefits beliefs on the probability of manure use. Benefits beliefs range from 1 to 5 across the horizontal axis. Archetypes are numbered from 1 to 4, with 1 being favorable for manure use, 4 being unfavorable, and 2 and 3 are moderate. Consistent with economic theory, benefits beliefs in figure 1 demonstrate both increasing and decreasing marginal effects, depending on the level of benefits beliefs and depending on the archetype. For example, for the two moderate archetypes [corn(−), cattle(+), problems(−) and corn(+), cattle(−), problems(−)], $\partial P/\partial Benefits$ reaches a maximum when benefits beliefs are at about 2, but declines

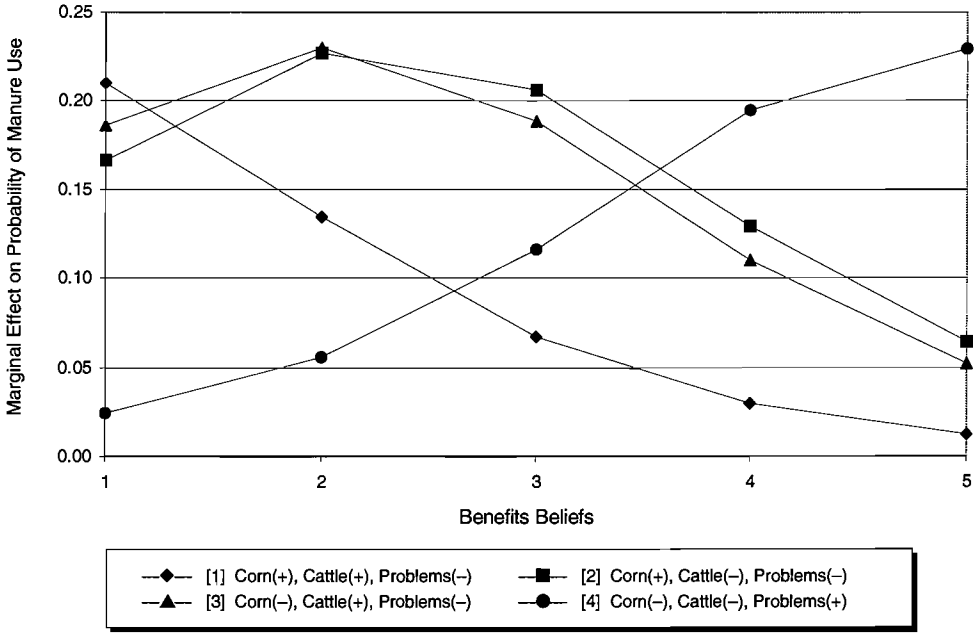

Figure 1. Marginal effects of benefits attitudes on probability of manure use, under various cattle/corn/problems scenarios

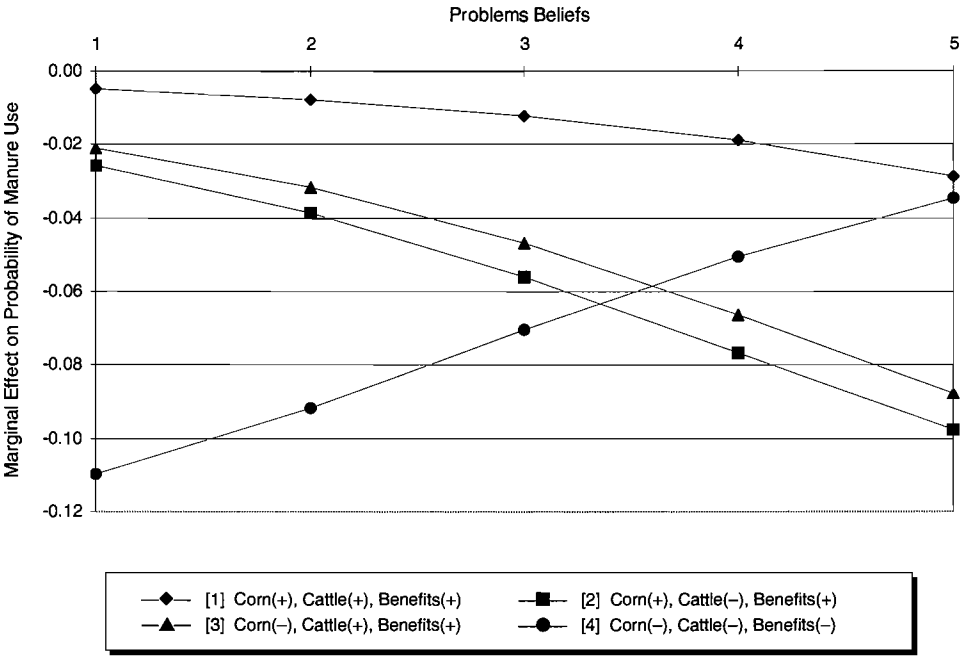

Figure 2. Marginal effects of problems beliefs on probability of manure use, under various cattle/corn/benefits scenarios

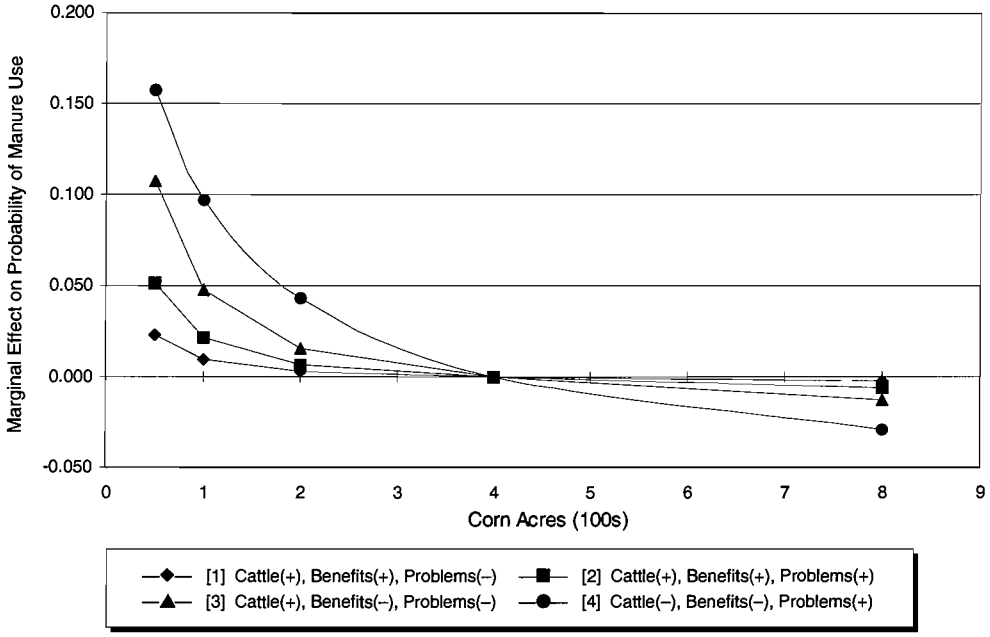

Figure 3. Marginal effects of acres of corn on probability of manure use, under various cattle/benefits/problems scenarios

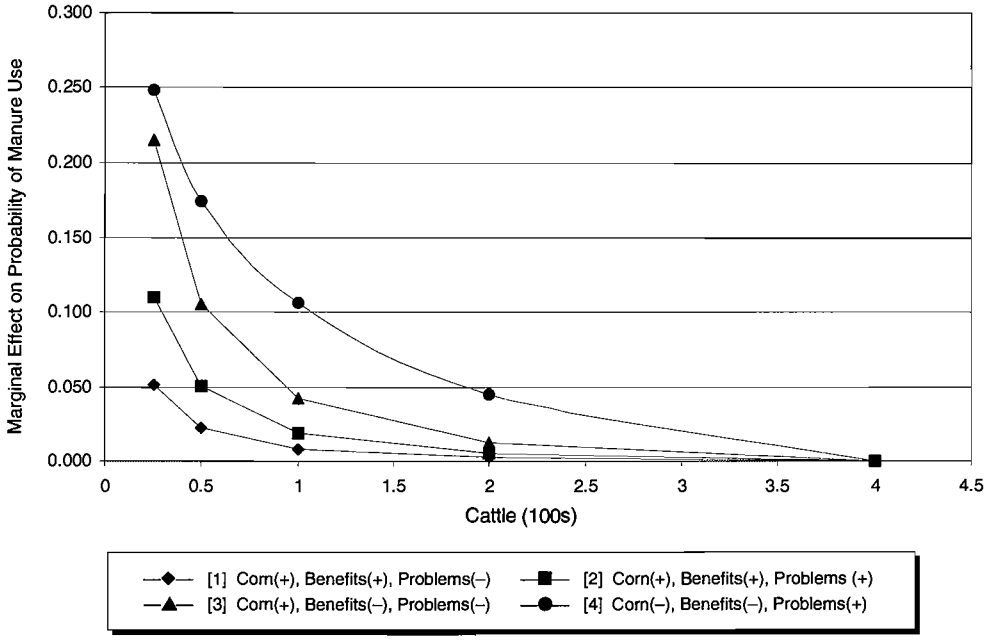

Figure 4. Marginal effects of number of cattle on probability of manure use, under various corn/benefits/problems scenarios

monotonically for larger values of benefits. In contrast, marginal adoption from benefits beliefs monotonically increase for the least favorable archetype and monitonically decrease for the most favorable situation.

While these results are consistent with economic theory, there is also a mathematical reason for the pattern seen in figure 1. Because the probability derivatives in a logistic model involve a factor of $P(1 - P)$, the marginal effect of a linear term like benefits will increase when P moves toward 0.5, and decrease thereafter.

Figure 2 displays the marginal effects of problems beliefs, with archetypes chosen similarly to figure 1. As previously noted, the marginal effects of problems beliefs, across the range of archetypes and across the range of problems beliefs, are consistently smaller in absolute size than those found for benefits beliefs. The typical absolute value of marginal changes for problems beliefs are around -0.06, which is about one-half as large as the typical absolute value seen in the benefits beliefs graphs of figure 2. For all situations except the low probability archetype 4 [corn(-), cattle(-), benefits(-)], the marginal effect of problems beliefs becomes steadily more negative (i.e., *larger* in absolute terms) as beliefs in manure problems increase. For this most unfavorable scenario, the marginal effects become steadily less negative as problems beliefs increase.

Figures 3 and 4 show the marginal impacts for the pressure variables. In both cases, cattle and corn, the impacts of more pressure on the probability of manure use are monotonically decreasing. In addition, the marginal impact for archetype 4 is greater for any given level of corn acreage or cattle herd size than it is for archetype 1, because there are diminishing marginal returns to the total effect of pressure and preference variables. For all archetypes in figure 3, the marginal impact of corn acreage is largest at low values, diminishes sharply, and becomes slightly negative for large values of corn acreage over 400 acres. Within the range of values examined here, the larger the corn acreage, the less impact any change in acreage would have on the probability of manure use.

Finally, figure 4 displays the marginal effects of the number of cattle on the probability of manure use. The results are quite similar to those for corn in figure 3. Again, the largest marginal effects occur at small values, with a rapid and monotonic decrease in marginal effect size as the number of cattle increases, with the $\partial P/\partial Cattle$ value becoming essentially zero by 200 head of cattle. As with corn acreage, the largest marginal effects occurred under the scenario least favorable to manure use (scenario 4), while the smallest effects occurred under the highly favorable scenario 1.

Conclusions

Our results show that, indeed, situational pressures and subjective preferences substantially affect decisions about whether to use manure. Therefore, in concurrence with Ribaudo et al.'s (2003) comprehensive study of the United States hog and dairy industries, our positive study of this adoption decision reveals behavior is not necessarily adequately captured by a restricted approach recognizing only nutrient substitution and transportation costs. We offer empirical support to show that willingness to apply is not predictable from current knowledge. This suggests that policy efforts designed to expand land application of manure cannot rely solely on understanding the relative price of manure compared to inorganic fertilizer, but should consider it as an adoption behavior

which must be understood in terms of contextual and perhaps subjective considerations on the part of the crop producer. Success in predicting willingness to apply manure is therefore likely to require information about the demand for manure rather than being readily modeled from physical considerations about factor substitution for inorganic nutrients.

The results of this analysis are consistent with economic rationale. The marginal impact of pressure and preference variables on probability is increasing when there is a small base, and decreasing when there is a large base. Our comparative analyses (table 5 and figures 1–4) show that a producer with the most favorable set of circumstances (high pressure from cattle and corn, and favorable views about the benefits and little concern about problems) would have more than a 98% probability of adopting manure use, compared to about 10% for a producer on the opposite end of the spectrum. The marginal impact of each of the four variables examined here—*Corn*, *Cattle*, *Benefits*, and *Problems*—on the probability of manure use varies distinctly across different scenarios and within its own values. However, a few simple generalizations are possible. First, the graphs shown in figures 1–4 support the economic notion of diminishing marginal changes as the base gets larger. Furthermore, the preference variables showed both increasing and decreasing returns, while the pressure variables were everywhere diminishing. In the case of corn, farms with more than 400 acres begin to decrease their use of manure as acres are added.

Our results do indicate that some particular strategies might increase the effectiveness of informational or education efforts to encourage manure use adoption. For example, findings suggest that working to increase beliefs in the agricultural benefits of manure use would yield more change than would efforts to diminish objections to manure application. In addition, the results imply that efforts to change attitudes would optimally be targeted at producers who face modest demand/supply pressures toward manure use. While we do not claim these particulars of our findings are fully generalizable to crop producers in other AFO-dense locales, we do believe that effective policy or educational initiatives elsewhere would also need to consider how the marginal effects of policy could vary across types of producers and situations.

Finally, it is worthwhile to mention a few limitations. First, when we began this study, we had no blueprint to follow from previous research. The addition of preference and pressures is only a beginning. It is quite likely that other factors are important and that pressure and preference variables can be improved in future studies. Moreover, it is extremely difficult to design a survey about manure because of the dimensionality involved in defining use—e.g., use involved accounting for applications that vary by year (application every year, every other year, or every third year) and within year (applications that supplement inorganic applications or that are concentrated on one field rather than dispersed and supplemented across multiple fields). Many hurdles will need to be overcome in order to truly gain knowledge about adoption. For example, a producer may apply manure multiple times on any field or may not apply manure every year. Furthermore, the producer may apply manure to one field and not another. Therefore, it is extremely difficult to draw conclusions about producer behavior.

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