Journal of Agricultural and Applied Economics, 44,1(February 2012):83–97

Effects of Manure Use and Use Restrictions on Variable Production Costs and Net Incomes for United States Corn Producers

Jayson Beckman and Michael Livingston

We utilize a treatment effects model to examine if there are differences in costs/profits for manure-using corn producers versus non-users. We find that manure users have lower per-acre operating costs via reductions in fertilizer and soil conditioner costs; however, the use of manure reduces grain yields and ultimately leads to no difference in profit. Separate results indicate that manure-use restrictions do not affect costs or profits; thus policies could be in place to regulate manure usage without impacting the costs/profit structure of the farm.

Key Words: nutrient management, treatment effects, micro-data

JEL Classification: Q1

The U.S. agricultural landscape has rapidly evolved with a shift to bigger and more specialized farms, along with a large increase in commercial fertilizer (hereafter fertilizer) use. This shift has resulted in less opportunity to jointly manage manure and plant nutrient needs within a single operation (Gollehon et al., 2001). With the changing structure of agricultural production, manure is increasingly being viewed negatively, with some labeling it as waste (Risse et al., 2001) or problematic due to disposal costs and environmental regulations. However, recent high and volatile fertilizer prices have illustrated the importance of manure as a relatively inexpensive nutrient source (Koehler, Johansson, and Peters, 2008).

Fertilizer prices and price volatility have increased substantially during the last decade. Increases in real prices (299% and 196% for phosphorous and nitrogen, respectively, since 2000) have contributed to lower net returns for crop producers, including corn (22%) and wheat (32%) producers who use fertilizer as a main input (Huang, Magleby, and Christensen, 2009). Furthermore, fertilizer prices are not expected to decline to their low pre-2000 levels, because U.S. fertilizer production has declined, global competition for fertilizers is increasing, and demand for natural gas (the main input in nitrogen fertilizer production) is increasing world-wide (Huang, Magleby, and Christensen, 2009).

U.S. crop producers have responded to higher fertilizer prices by reducing their use of fertilizers, using more manure as a substitute, and managing fertilizer use more carefully

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Jayson Beckman is an economist and Michael Livingston is a senior economist with the United States Department of Agriculture, Economic Research Service, Washington, DC.

The views expressed here are the authors' and do not necessarily represent those of the United States Department of Agriculture or Economic Research Service.

The authors gratefully acknowledge the helpful comments and suggestions from four anonymous reviewers. As always, any errors remaining are the sole responsibility of the authors.

(Table 1). However, opportunities for widespread manure substitution are limited, because manure can be costly to transport, even over short distances, and some cropland is located far from manure sources. Moreover, manure might not have the precise combination of nutrients needed for specific crops and fields. The first objective of this study is to examine the determinants of manure use for corn producers. We focus on corn because it is the most widely planted field crop in the United States and because corn accounts for the majority of fertilizer and animal manure applied to U.S. field crops (we estimate these amounts at 64 and 76% as detailed in Section 3, respectively).

The increase in the substitution of manure for fertilizers suggests that crop producers who manage livestock operations or cropland near livestock operations might be able to reduce operating costs and increase profits by reducing their use of fertilizers and increasing their use of manure. The second objective is to test these hypotheses using a maximum-likelihood, treatment-effects model that tests and corrects for sample selection bias and the potential endogeneity of manure use (Heckman, 1979; Heckman and Vytlacil, 2007). The model is estimated using field-level data collected from a national survey of U.S. corn producers for 2001.[1]

The ability to substitute animal manure for fertilizers might allow some farmers to reduce operating costs associated with producing crops; however, manure stockpiles and excess application rates can contribute to water and air pollution and negatively impact human health (Aillery et al., 2005; Diaz and Rosenberg, 2008; Ribaudo et al., 2003). To reduce the likelihood and level of pollution and the frequency of adverse health consequences, federal, state, and local governments have promulgated regulations that require many livestock and crop operations to develop and implement nutrient management plans that restrict application rates to agronomic standards.[2] Such regulations often stipulate the location of manure applications and require operators to spread manure over much larger land bases and transport any excess (Kaplan, Johansson, and Peters, 2004). As a result, the presence of restrictions might impede corn producers' ability to benefit from substituting manure for fertilizer. The third objective of this study is to test this hypothesis and examine how restrictions on manure use affect yield, operating cost, and profit for U.S. corn producers.

The potential environmental consequences of using manure are well established in the literature; however, empirical estimates of the impacts of manure use and use restrictions on yield, operating cost, and profit are needed to inform public policies designed to improve environmental outcomes associated with nutrient management practices. Results from our work indicate that, on average, corn producers who use manure do not have discernable differences in profit compared with non-users. Overall, the results indicate that manure use reduces per-acre operating costs; however, the use of manure reduces yields, effectively erasing any cost advantage of using manure. The results also indicate that, on average, manure-use restrictions do not alter yield, operating cost, or profit for U.S. corn producers who use manure.

Literature Review

Although many studies have examined the determinants of fertilizer use (e.g., Denbaly and Vroomen, 1993; Feinerman, Choi, and Johnson, 1990; Fuller, 1965; Griliches, 1958; Gunjal, Roberts, and Heady, 1980), relatively few have

[1] We utilized 2001 Agricultural Resource Management Survey (ARMS) data in this study, rather than the 2005 and 2010 data, for two reasons. First, official cost-of-production data are available for 2001, but not for 2005 and 2010. Second, using the 2001 data allowed us to examine average treatment effects during a period in which fertilizer prices were relatively stable, providing a more neutral experiment. Note, however, that we conducted the same analysis using unofficial cost-of-production data for 2005 with similar results that are available upon request.

[2] Federal restrictions (e.g., the Clean Water Act) tend to target livestock producers; while state and local restrictions often involve crop producers (e.g., the Clean Streams Law in the Commonwealth of Pennsylvania).

Table 1. Changes in Nitrogen Management Practices due to Higher Fertilizer Prices

Item	Corn (2005)	Soybeans (2006)	Cotton (2007)
	Percent		
Did they reduce the application rate of commercial nitrogen fertilizer	23.6	4.9	21.4
The amount reduced[a]	4.5	2.6	24.0
Did they change the type of commercial nitrogen fertilizer products applied	5.6	0.9	7.1
Did they increase the application rate of manure or other organic fertilizers	5.8	0.9	1.7
Did they manage fertilizer more closely, with such practices as soil testing, split applications	21.4	4.3	20.2

Sources: Phase II ARMS data for corn (2005), soybeans (2006), and cotton (2007).
[a] This is the percentage amount nitrogen was reduced for respondents who reported reducing the application rate of nitrogen fertilizer.

examined factors that influence manure use. Hoag and Roka (1995) compare manure management practices adopted by swine producers in Iowa and North Carolina to illustrate how such practices depend on industry structure and production possibilities. Swine producers in North Carolina specialize in swine production and typically purchase corn and soybean feed. Because they are less able to recycle manure nutrients on the farm, they view manure as waste that must be treated and disposed of and, as a result, tend to store manure in lagoons to reduce nutrient levels before applying it to low value crops, such as hay, that serve as nutrient sinks. Swine producers in Iowa, however, generally view manure as a valuable source of nutrients, because they manage more diverse farming operations, especially corn and soybean enterprises, and have adopted manure management practices that preserve manure nutrients.

Núñez and McCann (2008) examined the effects of farmer and farm characteristics and perceptions about manure on the likelihood of manure use by crop farmers in Iowa and Missouri with annual sales above $10,000 who do not manage livestock operations. Using survey data for the 2003 growing season, their estimates suggest that younger farmers and farmers with lower off-farm incomes are more likely to use manure than older farmers who receive more income off farm. Their results also indicate that crop farmers in Iowa are more likely to use manure than crop farmers in Missouri. They suggested that this is because farmers in Iowa assign a higher value to manure for use in producing crops than farmers in Missouri and because manure is more costly to transport in Missouri than in Iowa. Their estimates also suggest that the likelihood of manure use is higher for farmers who are concerned about water quality and believe that applying manure to cropland improves water quality. As we describe below, our empirical results are consistent with their findings; however, our results apply to corn producers throughout the United States with and without livestock operations.

Ghazalian, Larue, and West (2009) examined the impact of farmer and farm characteristics and input prices on the adoption of best management practices (BMPs) in the greater Chaudière region in Quebec where problems with water quality associated with livestock production have been acute. Using data from a survey of beef, dairy, and hog producers who also grew crops for 2006, their empirical results suggest that female farm operators are more likely to follow the examined BMP (injecting solid and liquid manure) than male operators. Respondents that resided on the farm, had a higher level of education, or managed larger operations were also more likely to adopt these practices. Similarly, Paudel et al. (2008) examined the impact of farmer and farm characteristics on the adoption of BMPs by dairy producers in Louisiana in a region with severe water quality problems. Their analysis of survey data suggests that dairy producers with more than a high school diploma or dairy producers with less debt are more likely to adopt waste and nutrient management practices designed to improve water quality.

The literature examining the impacts of manure use on yield, cost, and profit is scarce and has an international focus. Mutiro and Murwira (2004) conducted field trials with farmers in Zimbabwe to examine the response of corn yield, production cost, and profit to a fixed amount of manure and increasing levels of nitrogen fertilizer. The impacts of aerobic and anaerobic manure storage and alternative application methods were also examined. Profit was higher when manure was used without fertilizer, compared with a base case in which no nutrients were applied, and profit increased at a decreasing rate with the fertilizer application rate when the fixed amount of manure was also applied. However, they did not examine the marginal impact of manure use on yield, cost, and profit when fertilizer is also applied, which is the purpose of the current analysis.

Research examining the economics of manure use in developed countries has predominately focused on farms on which livestock enterprises are the primary focus. Roka and Hoag (1996) examined whether and how the value of manure in crop production affects animal replacement and slaughter weight for a representative swine finishing operation in North Carolina. Their results suggest that the costs of handling and applying manure exceed the value of the fertilizer it replaces and that animal replacement and slaughter weight decisions do not depend on manure value.

There has been a wealth of research examining the implications of environmental restrictions on manure management. Innes (2000) examined how economic incentives and regulations affect the number of farms raising livestock in a region, the distance between farms, the number of animals raised per farm, manure storage and cropland application decisions, and the external costs of environmental damages associated with manure spills and nutrient runoff. The theoretical analysis suggests that regulations governing waste-handling systems alone provide incentives that lead to excessive industry concentration and that social welfare can be improved by simultaneously limiting regional entry and the size of livestock facilities. The analysis also suggests that reducing incentives to apply manure close to production facilities by, for example, taxing fertilizers, will reduce nutrient runoff from manure applied to cropland.

Feinerman, Bosch, and Pease (2004) extended Innes' (2000) analysis in their empirical examination of Virginia legislation governing the application of manure based on agronomic rates for nitrogen and phosphorous (N- and P-based standards). They examined the impact of N- and P-based standards on the net returns from spreading manure using a spatial equilibrium model, in which crop producers choose whether to apply fertilizer only, manure only, or both to maximize profit. Under a scenario in which all crop producers are willing to use manure, their results suggest that the N- and P-based standards would lower the net returns from spreading manure by almost 5 and 15%, respectively. Transportation costs declined and increased, respectively, under the N- and P-based standards, and manure applications increased on corn, hay, and wheat acres and declined on pasture relative to the base case with no standards. However, their analysis did not account for the impact of manure use on yield. Our analysis suggests that manure use reduces corn grain yields, which would reduce manure demand and affect manure prices, applications across crops, transportation costs, and the net returns to spreading manure in equilibrium.

Huang, Magleby, and Christensen (2005) examined the economic impact of the 2002 U.S. Environmental Protection Agency (EPA) rule on dairy farms (concentrated animal feeding operations, or CAFOs) in the southwest using an optimization model and national survey data. They concluded that most CAFOs would experience a decline in net returns (of 6–17%), but that higher net incomes could be achieved if (among other things) operators used manure more efficiently. Using a farming-systems approach, Kaplan, Johansson, and

Peters (2004) examined the regional impacts of stricter manure-management standards (EPA, 2011) on CAFOs. They reported that the Appalachian, Southeast, and Pacific regions produced more manure per acre of cropland than other regions and might, as a result, be more influenced by regulations.

This short review of the existing literature has highlighted an important gap. Studies that have examined the determinants and economics of manure use and its regulation have utilized normative, optimization models, relied on limited data sets, and focused on specific regions. This study adds to the literature by examining the treatment effects of manure use and use restrictions on yield, production cost, and profit using a national survey of U.S. corn producers. The remainder of this article is organized as follows. In the next section, we describe the data we use and the extent and characteristics of manure use by U.S. crop producers to motivate the empirical analysis. The determinants of manure use are examined in the following section, and we describe the methods used to test whether and how manure use and use restrictions affect yield, cost, and profit in the subsequent section. We describe the empirical results in that section and provide a brief summary of the main findings in the concluding section.

Extent and Characteristics of Manure Use by U.S. Crop Producers

We use a large, nationally representative and comprehensive database known as the Agricultural Resource Management Survey (ARMS), which is the U.S. Department of Agriculture's (USDA's) primary source of information on the financial condition of farm businesses and households and farm production practices. Phase II surveys focus on operations that produce specific crops. A specific field planted to the crop is chosen at random for questions concerning land use and production practices, including manure applications. In particular, operators are asked to report the number of acres on the field that received manure, the animal source, how it was obtained and applied, and, among other questions, whether the application rate was influenced by federal, state, or local restrictions (however, in 2001 only state and local restrictions were asked). Phase II respondents are also surveyed during Phase III to enable linking data on production practices for specific crops to demographic data on farm operators and financial data at the farm level for each crop and livestock enterprise.

For this section, we examine Phase II ARMS data for barley (2003), corn (2005), cotton (2003), oats (2005), peanuts (2004), sorghum (2003), soybeans (2006), and wheat (2004) to estimate the extent and characteristics of manure use and use restrictions. We combined estimates of manure-acreage shares and application rates for 2003–2006 with recent estimates of acres planted to these crops in 2006 (USDA, 2008) to estimate the extent of manure use in 2006. Assuming manure-acreage shares and application rates remained constant during 2003–2006, an estimated 14.2 million acres planted to these eight crops received manure in 2006. Seventy percent of the acres that received manure were corn acres. In decreasing acreage levels, soybean, wheat, oats, and cotton fields accounted for over 28% of the acres that received manure, and barley, peanut, and sorghum fields accounted for the remaining 2%.

Management of a livestock operation was an important determinant of manure use for barley, corn, oat, soybean, and wheat farmers, whereas proximity to a livestock operation was an important determinant of manure use for peanut and cotton farmers. Over 80% of barley, corn, oat, soybean, and wheat producers and over 70% of sorghum producers who used manure relied on on-farm sources (Table 2) primarily from beef or dairy cattle, followed by hogs. Almost 52% of the peanut producers and 59% of the cotton producers who used manure purchased poultry manure from nearby operations. Peanuts and cotton are produced primarily in the southeast, where the majority of broilers are produced, and the majority of peanut (70%) and cotton (80%) manure-using producers did not manage livestock operations.

Producers who manage large crop operations generally specialize in crop production and do not manage livestock enterprises; therefore, manure is not as readily available on-farm. Producers who manage smaller crop operations

Table 2. U.S. Crop Producers Who Used Manure (Percentages) in 2006

	Barley	Corn	Cotton	Oats	Peanuts	Sorghum	Soybean	Wheat
Manure acquisition[a]								
Produced their own	87.2	87.6	22.2	92.9	29.0	71.1	82.4	82.3
Purchased	3.5	3.6	59.5	0.8	51.8	25.1	5.7	5.6
Obtained at no cost	9.1	7.4	14.9	3.9	19.2	3.9	9.6	4.2
Obtained with compensation	0.2	1.4	3.5	2.3	0.0	0.0	2.3	7.9
Manure source[a]								
Beef cattle	36.1	17.8	25.2	37.0	16.9	80.8	33.3	62.4
Dairy cattle	54.1	61.8	17.0	57.8	0.0	1.7	36.0	26.7
Swine	3.8	12.8	0.0	2.3	0.0	15.9	14.2	6.4
Poultry	4.6	5.2	57.6	1.0	83.1	1.6	13.4	3.0
Other[b]	1.4	2.5	0.2	2.0	0.0	0.0	3.1	1.5
Planted corn acres[c]								
First quartile	42.3	42.9	6.2	32.3	2.1	5.4	9.4	5.2
Second quartile	17.4	32.2	3.9	26.4	3.2	1.1	6.4	1.5
Third quartile	4.2	17.8	5.9	24.5	2.8	1.2	2.6	2.6
Fourth quartile	2.4	13.3	1.5	19.5	3.5	0.7	2.7	0.6
Manure application rate affected by restrictions[a]	7.1	20.6	24.9	6.7	17.3	7.3	17.8	3.5

Sources: Phase III ARMS data for barley (2003), corn (2005), cotton (2003), oats (2005), peanuts (2004), sorghum (2003), soybeans (2006), and wheat (2004).

[a] Percent of crop producers who used manure.

[b] Other manure sources include sheep, equine, municipal sludge, food waste, and other respondent-specified sources.

[c] Percent of crop producers in each planted acreage category.

are more diversified and more likely to raise livestock and have, as a result, better access to manure nutrients. Therefore, smaller crop operations were more likely to use manure. We sorted producers of each of the eight crops into four acreage categories and calculated the percentages of producers in each of the categories who used manure (Table 2). Forty-three percent of corn producers with planted acres in the smallest quartile used manure, compared with only 13% in the largest quartile. A similarly strong linkage between planted acres and manure use emerged for oat and barley producers. Peanut was the only crop without a clear relationship between planted acreage and manure use.

Restrictions influenced manure application rates on almost 25 % of cotton acres, 21% of the corn acres receiving manure, 18% of the soybean acres, 17% of the peanut acres, and between three and eight percent of the acres planted to the other crops (Table 2). Among producers whose application rates were influenced by restrictions, nitrogen requirements were cited as a limiting factor by 80% of the corn producers, 70% of the soybean producers, and 90% of the cotton producers. Phosphorus requirements also played a major role for corn (71%) and soybean (57%) producers.

The survey data strongly suggest that corn is the most important crop to consider when examining the determinants of manure use and use restrictions and their impacts on yield, operating cost, and profit. We therefore focus on corn in the remainder of this article. In the next section, we examine factors that influence manure use and use restrictions and, in the following section, the impacts of manure use and use restrictions.

The Determinants of Manure Use

Probit Model

We used a probit model to examine the characteristics of manure users and farms on which manure is used. The probit model is based on a latent regression, $z_i^* = \mathbf{x}_i^{\prime}\beta + u_i$, where $\mathbf{x}_i$ is a k-by-one vector of explanatory variables for respondent i, β is a k-by-one vector of coefficients, / is the transpose operator, and u_i is a standard-normal disturbance. The model is estimated by specifying a dummy variable, z_i, that takes the value one if respondent i used manure, and zero otherwise, and by assuming that $z_i = 1$ if $z_i^* > 0$, and $z_i = 0$ if $z_i^* \leq 0$ (e.g., Greene, 2008).

We included farmer characteristics (age of the operator and a dummy variable indicating whether the operator had some college experience), regional dummies, the total amount of acres harvested for grain and silage at the farm level, and the number of livestock on hand at the farm level as explanatory variables. We also included federal and private insurance dummies to explore possible linkages with manure use. We included farmer characteristics to account for systematic effects on the likelihood of manure use due to age and educational attainment that might confound estimates of treatment effects. Núñez and McCann (2008) found that those who used manure on their crop farms tended to be younger. They also found that crop farmers with at least some college were less likely to use manure; however, the effect was not statistically significant.

We included regional dummies to account for differences in farming systems (e.g., Hoag and Roka, 1995; Kaplan, Johansson, and Peters, 2004; Núñez and McCann, 2008).[3] Dairy farms are concentrated in the Lake States and Northeast, and many operators grow corn for silage as a source of feed and recycle manure nutrients on the farm. In addition, farms specializing in grain and oilseed production, on which manure use is less likely, are concentrated in the Corn Belt. In our 2001 sample, dairy production accounted for the largest portion of agricultural sales for 336 of the respondents, and 229 (over 68%) of those respondents reported applying manure to the surveyed cornfield. Almost 38 and 33% of the 229 respondents were in the Lake States and Northeast, respectively, and almost 18% were in the Corn Belt. Grains and oilseeds accounted for the largest portion of sales for 988 of the respondents, and 903 (over 91%) of those respondents did not apply manure to the surveyed cornfield. Almost 45 and 27% of the 903 respondents were in the Corn Belt and Northern Plains, respectively. Beef cattle accounted for the largest portion of sales for 242 of the respondents, 181 (almost 75%) did not use manure, and almost 40% of the 181 respondents were in the Northern Plains. Hogs accounted for the largest portion of sales for 70 respondents, 28 and 42 applied and did not apply manure, respectively, and over 71 and 60% of the manure users and non-users were in the Corn Belt. Poultry and eggs accounted for the largest portion of sales for 43 respondents, 34 (79%) applied manure, and almost 24 and 27% of those respondents were in the Appalachian, Corn Belt, and Northeast regions. We therefore expect manure use to vary regionally and to be more likely in the Lake States and Northeast and relatively less likely in the Corn Belt and Northern Plains.

We included corn acres harvested for grain and silage to account further for differences in farming systems. Our analysis of the extent and characteristics of manure use suggests that the likelihood of manure use declines with the number of planted corn acres, because the likelihood the farmer specializes in corn production increases with the number of planted corn acres. Because the majority of the corn producers reported planting the cornfield surveyed in Phase II with the intention of harvesting it for grain, we expect the coefficient estimate on corn acres harvested for grain to be negative. However, we expect the coefficient estimate to be positive on corn acres harvested for silage, because corn producers typically grow corn for silage to feed to their livestock and also typically recycle livestock manure on those acres.

[3] The surveyed states (and numbers of respondents) and regions are as follows. The Appalachian region includes Kentucky (102) and North Carolina (69); the Corn Belt includes Illinois (142), Indiana (129), Iowa (119), Missouri (95), and Ohio (129); the Lake States include Michigan (82), Minnesota (113), and Wisconsin (109); the Mountain region includes Colorado (88); the Northeast includes New York (45) and Pennsylvania (97); the Northern Plains includes Kansas (105), Nebraska (106), North Dakota (64), and South Dakota (100); the Southeast includes Georgia (51); and the Southern Plains includes Texas (92).

We also included beef and dairy cattle, hogs, and poultry on hand at the end of 2001 to account further for differences in farming systems. We expect the likelihood of manure use to increase with the number of livestock on hand, simply because the amount of manure on hand increases with livestock numbers. Note that we included numbers of livestock on hand, as opposed to dummy variables indicating whether, for example, dairy cattle were on hand, because including numbers of livestock improved model fit. Although we included crop insurance dummies, we have no expectations regarding how the likelihood of manure use depends on the purchase of federal or private crop insurance.

We also used a probit model to examine the determinants of manure-use restrictions for manure users. We set z_i to one if respondent i indicated that the manure application rate was influenced by state or local restrictions, and to zero otherwise. (We did not examine separate models for N- and P-based restrictions.) The previous discussion suggests that the number of livestock on hand might help explain the likelihood that a corn producer might be subject to restrictions on manure use. We also included regional fixed effects to account for geographical variation in manure-use restrictions; however, we did not include a dummy variable for the Southern Plains, because none of the respondents from that region reported being subject to restrictions.

Several indicators of environmental influences on manure application were included as explanatory variables, including a dummy variable indicating whether the surveyed cornfield contained a wetland or was designated as highly erodible. We also included variables describing the soil conservation practices adopted by the respondent, including the number of such practices adopted, a dummy variable indicating whether a written soil conservation plan was followed, and a dummy variable indicating whether a comprehensive nutrient management plan specifying practices for fertilizer and animal manure was followed. Because large livestock production enterprises are often required to follow written soil conservation and comprehensive nutrient management plans that restrict manure use and application rates, especially in environmentally sensitive areas, we expect the likelihood the manure application rate was affected by state or local restrictions to be higher for respondents who followed written soil conservation and comprehensive nutrient management plans.

Descriptive Statistics and Results

Descriptive statistics for the variables used in the probit model to explain manure use are reported in Table 3. Almost 25% of the 1,837 respondents applied manure to cornfields surveyed in the Appalachian (32), Corn Belt (108), Lake States (131), Mountain (21), Northeast (101), Northern Plains (43), Southeast (17), and Southern Plains (5) regions. The average respondent harvested over 374 and 35 acres of corn for grain and silage, respectively; however, the standard deviation and the range, the latter of which is not shown because these data are confidential, indicate that both quantities vary considerably. The average respondent was almost 52-years-old and had 113 beef cattle, 67 dairy cattle, 196 hogs, and almost 2,800 poultry on hand. Almost half of the respondents had some college education, the majority purchased federal crop insurance (63%), and private crop insurance was not as common (17%). Most of the respondents were located in the Corn Belt (33%) (this was the base), followed by the Northern Plains (20%).

Descriptive statistics for the variables used in the probit model to explain whether manure application rates were affected by state or local restrictions are reported in Table 4. Over 22% of the 458 respondents who used manure in the Appalachian (17), Corn Belt (36), Lake States (23), Northeast (17), and Southeast (5) regions were affected by state or local restrictions. Comparing the manure users to all of the respondents in the sample, manure users tended to have 14 less beef cattle, but more dairy (114), hogs (48), and poultry (5,333). The one-and-a-half times the amount of dairy cattle for manure users certainly fits with Table 2, which indicates that the largest source of manure for U.S. corn producers is dairy. Of the seven soil

Table 3. Maximum Likelihood Estimates of the Probit Model of Manure Use

Variable	Coefficient	Standard Error	Marginal Effect	Standard Error	Mean	Standard Deviation
Constant	−0.218	0.190	−0.059	0.052		
Acres harvested for grain	−0.001***	1.2E-04	−2.3E-04 ***	2.9E-05	374.4	617.1
Acres harvested for silage	0.001*	4.9E-04	2.5E-04 *	1.3E-04	35.4	108.7
Beef cattle on hand on 12/31/2001	2E-04***	7.6E-05	6E-05***	2.0E-05	112.9	484.8
Dairy cattle on hand on 12/31/2001	9E-04***	2.1E-04	3E-04***	5.7E-05	67.3	243.5
Hogs on hand on 12/31/2001	1E-04***	3.4E-05	4E-05***	9.1E-06	195.9	991.2
Poultry on hand on 12/31/2001	1E-05***	2.1E-06	3E-06***	6.0E-07	2,799.0	20,070.6
Operator's age	−0.007**	0.003	−0.002**	0.001	51.6	11.7
= 1 if operator had some college	−0.234***	0.076	−0.063***	0.020	0.455	0.498
= 1 federal crop insurance purchased	−0.248***	0.077	−0.069***	0.022	0.630	0.483
= 1 private crop insurance purchased	−0.040	0.103	−0.011	0.027	0.172	0.378
= 1 if operation was in Appalachian	−0.244*	0.140	−0.061*	0.031	0.093	0.291
= 1 if operation was in Lake States	0.631***	0.102	0.200***	0.036	0.166	0.372
= 1 if operation was in Mountain	0.304*	0.176	0.092	0.058	0.048	0.214
= 1 if operation was in Northeast	1.060***	0.137	0.372***	0.053	0.077	0.267
= 1 if operation was in Northern Plains	−0.202*	0.114	−0.052*	0.028	0.204	0.403
= 1 if operation was in Southeast	0.211	0.210	0.062	0.067	0.028	0.164
= 1 if operation was in Southern Plains	−0.845***	0.256	−0.156***	0.027	0.050	0.218

Notes: Merged Phase II and Phase III ARMS data for corn producers for 2001 were used. Estimates are statistically significant at the 0.01***, 0.05**, and 0.1* levels. For a dummy variable, the marginal effect is the change in the estimated probability the dependent variable is one, when the dummy variable is one and zero, with the remaining variables evaluated at their means. For a continuous variable, the marginal effect is the derivative of the estimated probability the dependent variable is one with respect to the variable, with all variables evaluated at their means. The standard errors for the marginal effects were computed using the delta method (Greene, 2008).

Dependent variable = 1 if respondent used manure. Observations: 1837.

Log likelihood, unrestricted, L_u −784.26; Log likelihood, restricted, L_r −1031.63; Chi squared statistic, $-2(L_r - L_u)$ 494.82***. McFadden Pseudo R-squared 0.24.

conservation practices queried in the ARMS, manure users averaged practicing a little less than one of them. More manure users had written soil conservation plans (30%) than nutrient management plans (14%). More manure-using corn producers were located in the Lake States (29%), followed by the Corn Belt (25%) and the Northeast (22%).

As expected, the estimates indicate that respondents who harvested more acres for grain were less likely to use manure and respondents who harvested more acres for silage were more likely to use manure (Table 3). As was also expected, the likelihood of manure use increased with numbers of livestock on hand. Age and educational attainment were negatively related to the likelihood of manure use, as was the federal crop-insurance dummy. The first two results are consistent with Núñez and McCann's (2008) findings, although the negative coefficient

Table 4. Maximum Likelihood Estimates of the Probit Model of Manure Use Restrictions

Variable	Coefficient	Standard Error	Marginal Effect	Standard Error	Mean	Standard Deviation
Constant	−1.185***	0.184	−0.428***	0.067		
Beef cattle on hand on 12/31/2001	8E-05	1.8E-04	2E-05	4.8E-05	98.3	433.3
Dairy cattle on hand on 12/31/2001	3E-04*	1.8E-04	8E-05*	4.7E-05	181.1	377.7
Hogs on hand on 12/31/2001	3E-04***	7.4E-05	8E-05***	2.0E-05	243.8	933.4
Poultry on hand on 12/31/2001	1E-05***	2.7E-06	3E-06***	7.4E-07	8,132.1	34,468.1
Soil conservation practices adopted	0.208***	0.078	0.055***	0.021	0.869	1.044
= 1 nutrient management plan	0.699***	0.208	0.223***	0.075	0.135	0.342
= 1 written soil conservation plan	0.243	0.188	0.067	0.054	0.297	0.457
= 1 highly erodible cornfield	−0.351	0.221	−0.083*	0.047	0.175	0.380
= 1 cornfield contained a wetland	−0.844	0.739	−0.147**	0.069	0.028	0.166
= 1 if operation was in Appalachian	0.723**	0.288	0.238**	0.109	0.070	0.255
= 1 if operation was in Lake States	−0.293	0.208	−0.073	0.049	0.286	0.423
= 1 if operation was in Mountain	−0.389	0.443	−0.087	0.080	0.046	0.046
= 1 if operation was in Northeast	−0.472**	0.224	−0.110**	0.045	0.221	0.221
= 1 if operation was in Northern Plains	−0.400	0.350	−0.091	0.065	0.094	0.094
= 1 if operation was in Southeast	0.029	0.390	0.008	0.106	0.037	0.037

Notes: Merged Phase II and Phase III ARMS data for corn producers for 2001 were used. Estimates are statistically significant at the 0.01***, 0.05**, and 0.1* levels. For a dummy variable, the marginal effect is the change in the estimated probability the dependent variable is one, when the dummy variable is one and zero, with the remaining variables evaluated at their means. For a continuous variable, the marginal effect is the derivative of the estimated probability the dependent variable is one with respect to the variable, with all variables evaluated at their means. The standard errors for the marginal effects were computed using the delta method (Greene, 2008).

Dependent variable = 1 if manure use was affected by restrictions. Observations: 458.

Log likelihood, unrestricted, L_u −188.70; Log likelihood, restricted, L_r −244.13; Chi squared statistic, $-2(L_r - L_u)$, 15 *df* 110.85***.

McFadden Pseudo R-squared 0.23

estimate on the education dummy variable in their sample was not statistically significant. Respondents in the Appalachian, Northern Plains, and Southern Plains regions were less likely to use manure than respondents in the Corn Belt (this was the base); and respondents in the Lake States and Northeast regions were more likely to use manure. As indicated previously, this is likely because respondents from the Lake States and Northeast regions were more likely to manage large dairy operations, the primary type of manure applied to U.S. cornfields, than respondents from the other regions.

Maximum likelihood estimates for the probit model of manure-use restrictions are reported in Table 4. Note that these estimates are based on the 458 observations reported by the respondents who used manure. The likelihood that a respondent's manure application rate was affected by state or local restrictions increased with the number of dairy cattle, hogs, and poultry on hand at the end of 2001. The likelihood did not depend on the number of beef cattle

Table 5. Maximum Likelihood Estimates of Profit

Variable	Coefficient	Standard Error	Mean	Standard Deviation
Constant	108.898***	9.503		
Ratio of livestock sales to total agricultural sales	−12.218	8.787	0.395	0.411
Yield goal	0.110***	0.038	152.7	48.1
= 1 majority gross income from grains/oilseeds	−3.150	7.565	0.538	0.499
= 1 majority gross income from hogs	28.019**	14.225	0.038	0.192
= 1 majority gross income from dairy products	−34.439***	10.337	0.183	0.387
= 1 majority gross income from beef cattle	−27.421***	10.186	0.132	0.338
= 1 majority gross income from poultry and eggs	67.350***	13.858	0.023	0.151
Percentage surveyed cornfield used as non-Bt refuge	−0.072	0.162	3.812	14.104
= 1 if National Resource Conservation Service classified part of field as highly erodible	9.680*	5.237	0.188	0.391
= 1 if reduced fertilizer	−6.798	8.156	0.111	0.314
= 1 if increased manure	−9.873	13.732	0.019	0.137
= 1 if managed fertilizer more carefully	−11.325	9.423	0.083	0.276
= 1 if operation was in Appalachian	−22.296***	7.814	0.093	0.291
= 1 if operation was in Lake States	−31.676***	7.067	0.165	0.372
= 1 if operation was in Mountain	−18.028*	9.559	0.048	0.214
= 1 if operation was in Northeast	3.763	9.173	0.077	0.267
= 1 if operation was in Northern Plains	−36.530***	6.636	0.204	0.403
= 1 if operation was in Southeast	−1.778	11.787	0.028	0.164
= 1 if operation was in Southern Plains	−77.473***	8.675	0.050	0.218
= 1 if used manure, θ	−90.569***	10.627	0.249	0.433
Standard deviation profit disturbance, σ_ε	86.594***	1.736		
Bivariate normal correlation coefficient, ρ	0.584***	0.054		

Notes: Merged Phase II and Phase III ARMS data for corn producers for 2001 were used. Estimates are statistically significant at the 0.01***, 0.05**, and 0.1* levels. These estimates maximize likelihood Equation (2). Coefficient estimates for the manure-probit are suppressed because of space limitations. Note that the coefficient estimates are similar (in magnitude and sign) but different from those reported in Table 2.
Dependent variable profit per acre (gross value of production minus operating costs). Observations: 1837.
Log likelihood −11441.

on hand. As expected, the likelihood a manure using corn producer was subject to restrictions also increased with the number of soil conservation practices adopted and was higher for respondents who followed a comprehensive nutrient management plan. Finally, the estimates indicate that respondents with operations in the Corn Belt and Northeast regions were less likely to be influenced by state or local restrictions and that operations in the Appalachian region were more likely to be influenced by restrictions.

Does Manure Use Affect Yield, Operating Cost, and Profit?

Treatment Effects Model

In the previous section we used probit models to examine the likelihood survey respondents applied manure to the surveyed cornfield and the likelihood that the manure application rate of manure users was affected by state and local restrictions. In this section we use those models to account for systematic differences in respondents

Table 6. Maximum Likelihood Estimates for Treatment Effects

	Manure Use		Manure-Use Restrictions	
	Observations	1837	Observations	458
	Right-hand Side	41	Right-hand Side	41
Variable	Treatment Effect	Standard Error	Treatment Effect	Standard Error
Profit	−2.346	5.355	−14.611	11.267
Operating costs	−10.406**	4.381	4.447	6.978
Fertilizer and soil conditioner costs	−13.321***	1.904	−4.193	3.797
Grain yield	−11.840***	3.119	−8.279	8.425
Silage yield	2.793***	0.287	0.938	1.005

Notes: Merged Phase II and Phase III ARMS data for corn producers for 2001 were used. Estimates are statistically significant at the 0.01***, 0.05**, and 0.1* levels. Treatment effects were estimated using Equation (3) in the text, which are based on coefficient estimates that maximize likelihood Equation (2). Standard errors for the treatment effects were estimated using the delta method (Greene, 2008).

who used and did not use manure (and systematic differences in manure users who were and were not affected by restrictions) in order to identify the effect of manure use (and manure use restrictions) on yield, operating cost, and profit. We used the following model to estimate each treatment effect:

$$y_i = \mathbf{w}_i^{/}\boldsymbol{\alpha} + \theta z_i + \varepsilon_i$$
$$z_i^* = \mathbf{x}_i^{/}\boldsymbol{\beta} + u_i > 0 \Rightarrow z_i = 1, z_i^* \leq 0 \Rightarrow z_i = 0 \quad (1)$$
$$\begin{pmatrix}\varepsilon_i \\ u_i\end{pmatrix} \sim \mathrm{N}\left(\begin{pmatrix}0 \\ 0\end{pmatrix}, \begin{pmatrix}\sigma_\varepsilon^2 & \rho \\ \rho & 1\end{pmatrix}\right).$$

We assumed the disturbance terms, ε_i and u_i, are bivariate normal with correlation coefficient, ρ. The first equation is the treatment-effect equation, describing the relationship between, for example, profit, explanatory variables $\mathbf{w}_i$, and the potentially endogenous dummy variable, z_i, which indicates whether respondent i used manure. The following explanatory variables, $\mathbf{w}_i$, were included in the treatment-effect equation: the ratio of livestock sales to total sales; the respondents' reported yield goal; dummy variables indicating the primary source of gross income; the percentage of the surveyed cornfield used as a refuge for Bt resistance management; a dummy variable indicating whether the Natural Resource Conservation Service classified any part of the field as highly erodible; dummy variables indicating whether higher fertilizer prices led the respondent to reduce fertilizer use, increase manure use, and manage fertilizers more carefully; and the region dummies.

Estimation of the first equation in Equation (1) separately can lead to biased and inefficient estimates, because manure use is endogenous (Heckman, 1979; Heckman and Vytlacil, 2007).[4] Heckman's (1979) two-step procedure and maximizing the joint likelihood equation associated with Equation (1) (e.g. Greene, 2008) are common methods used to obtain unbiased and efficient coefficient estimates. We used the latter method by maximizing the joint likelihood equation,

$$\log \mathrm{L} = \sum_{i=1}^{n} \log\left(\frac{\exp(-\varepsilon_i^2/2\sigma_\varepsilon^2)}{\sigma_\varepsilon\sqrt{2\pi}}\right.$$
$$\left.\Phi\left(\frac{(2z_i - 1)(\rho\varepsilon_i/\sigma_\varepsilon + \mathbf{w}_i^{/}\boldsymbol{\alpha})}{\sqrt{1-\rho^2}}\right)\right), \quad (2)$$
$$\text{where } \varepsilon_i = y_i - \boldsymbol{\beta}^{/}\mathbf{x}_i - \theta z_i,$$

and Φ is the standard-normal cumulative distribution function. We examined the average

[4] This is because individuals who use manure might, on average, be more (or less) profitable producing corn than producers who do not use manure and, as a result, the reason profits are higher (or lower) for the former group might have little to do with the substitution of manure for fertilizer and more to do with the types of farms on which manure is used and the characteristics of farmers who use manure. For example, manure use is more likely on smaller corn operations, which are often less profitable than larger corn operations.

treatment effect of, for example, manure use, z_i, on profit, y_i, using coefficients obtained from maximizing likelihood Equation (2) to estimate the difference in profits for corn producers who used and did not use manure (Greene, 2008),

$$
\text{(3)} \quad \begin{aligned} &E[y_i|z_i = 1, \mathbf{w}_i, \mathbf{x}_i] - E[y_i|z_i = 0, \mathbf{w}_i, \mathbf{x}_i] \\ &= \theta + \frac{\rho\sigma_\varepsilon\varphi(\mathbf{w}_i'\boldsymbol{\alpha})}{\Phi(\mathbf{w}_i'\boldsymbol{\alpha})(1 - \Phi(\mathbf{w}_i'\boldsymbol{\alpha}))}, \end{aligned}
$$

where ϕ denotes the standard-normal probability density function. The second term on the right-hand side of treatment-effect Equation (3) accounts for the self-selected nature of manure use on profit, by accounting for the determinants and likelihood of manure use and the correlation between random fluctuations in manure use and profit, $\rho\sigma_\varepsilon$. Standard errors for the treatment effects were calculated using the delta method, and we estimated the model using NLOGIT.

Descriptive Statistics and Results

Yields, operating costs, and profits examined in this section are for the surveyed cornfields, and Table 5 presents descriptive statistics for the variables used in the treatment-effects equation, $\mathbf{w}_i$.[5] The average corn producer obtained almost 40% of farm sales from livestock production; however, most of the respondents obtained the majority of their income from grains and oilseeds (54%), followed by dairy products (18%). The average yield goal was 153 bushels/acre, and average profit from corn production for the entire sample was $44 per harvested acre.

The maximum likelihood estimates for Equation (1) in Table 5 indicate that profit increased with the yield goal. The ratio of livestock sales to total agricultural sales, however, is statistically insignificant. Results indicate that deriving the majority of gross income from hogs and poultry increased the returns to corn production; however, deriving the majority of income from dairy products or beef cattle reduced profits. This is likely because corn producers who manage dairy and beef operations harvest more acres for silage, which is less profitable, and because corn producers who manage hog and poultry operations (since hogs and poultry are typically given a processed feed diet), harvest more acres for grain. The estimates indicate that profits were higher on fields classified as highly erodible. The dummy variables pertaining to reducing fertilizer use, increasing manure use, or managing fertilizer more carefully because of high fertilizer prices were statistically insignificant. Profits in the Corn Belt were the highest according to our estimates, as all other regions have a negative (and significant) estimate, or their estimate is not significant.

Estimates of the average treatment effects (Equation (3)) of manure use and use restrictions are reported in Table 6. Manure use did not affect profit per acre at the 10% significance level. Manure use reduced operating costs $10.41 per acre ($p = 0.0175$), because of reductions in fertilizer and soil conditioner costs of $13.32 per acre ($p < 1e-4$). However, although manure use increased silage yield 2.79 tons per acre ($p < 1e-4$), manure use reduced grain yields 11.84 bushels per acre ($p = 1e-4$). The final result is that there is no statistical impact on profit for corn producers who used manure compared with those who did not use manure. The reduction in revenue due to lower grain yield cancelled out any reduction in cost from substituting manure for fertilizer.

The results also indicate that manure-use restrictions have no statistically significant impact on yields, costs, and profit. These results differ from studies that have indicated that restrictions impact profits; however, those studies focused on particular regulations in specific states or regions. Our results suggest that state or local restrictions in 2001 did not have a statistically significant impact on profit when averaged across manure

[5] The statistics in Table 5 are for the entire sample. Interesting comparisons can be made for the respondents who used manure, including in particular the value of livestock sales to total sales (76%), the yield goal (170 bushels/acre), and the dummy variable indicating the largest portion of income was from dairy products (50%). Descriptive statistics for the other variables are similar to the entire sample.

users in the ARMS data we examined in this study.[6]

Conclusions

Manure use is a highly contentious issue with several pieces of legislation guiding application rates, location, and timing. The 1976 Clean Water Act set federal standards for the disposal of livestock manure, and subsequent additions to the Act have tightened regulations. Further, states and localities often have regulations in place targeting the disposal of manure by livestock producers, and the application of manure by crop producers. In this study we used data collected from a national survey of corn producers for the 2001 growing season to examine factors that influence the likelihood of manure use and the likelihood that manure application rates for manure users were affected by state and local restrictions.

Our results indicate that farmers who managed larger corn-for-grain enterprises were less likely to use manure. As expected, the likelihood of manure use increased with the amount of corn harvested for silage and numbers of different types of livestock on hand. (Note that we do not know whether the respondents used manure solely for disposal or for nutrients). Corn producers in the Appalachian, Northern Plains, and Southern Plains regions were less likely to use manure than corn producers in the Corn Belt. Corn producers in the Northeast and Lake States were more likely to use manure, because respondents from these regions were more likely to manage large dairy operations, the primary type of manure applied to U.S. cornfields, than respondents from the other regions. In addition, farms tend to be smaller in the Northeast and Lake States than in the other regions, and manure use is more likely on smaller corn operations. Interestingly, the age of the farm operator and whether the operator had some college experience were negatively related to manure use.

Previous literature has indicated that manure production increases costs for livestock producers, due to transportation and disposal costs; however, very little has been said regarding crop producers. In this study, we examined a treatment-effects model to determine whether and how corn yields, production costs, and returns differ for manure users versus nonusers. The results indicate that manure users have lower operating costs, due to reductions in fertilizer and soil conditioner costs; however, the use of manure reduces grain yields and ultimately leads to no difference in profit. We also examined whether manure-use restrictions affect yield, cost, and profit and found no statistically significant impacts. This result suggests that manure application restrictions can benefit the environment without adversely affecting returns to corn production.

More stringent CAFO policies regulating the application of manure were adopted in 2003 (to be implemented by 2006) and revised in 2008 (EPA, 2011). A potentially beneficial avenue for future study would use the 2010 ARMS data to examine how tighter restrictions have altered manure use by corn producers. In addition, the 2010 data could also be used to examine differences in manure use due to higher fertilizer prices. Table 5 indicates that manure use was increased by only 2% of corn producers in 2001 due to high fertilizer prices, while Table 1 indicates that in 2005 this percentage increased to almost 6% (when fertilizer prices were higher than 2001). Thus we would expect that the 2010 survey would show an even larger increase in manure use due to higher fertilizer prices.

[Received September 2010; Accepted September 2011.]

[6] We also attempted to examine average treatment effects of manure-use restrictions for each region separately using similar models, the main difference being the exclusion of regional dummies. We found no significant effect on profits for the Corn Belt and Lake States and were unable to estimate average treatment effects for the other regions separately due to problems associated with collinear regressors.

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