At What Rate Do Farmers Substitute Manure For Commercial Fertilizers?

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Paper prepared for presentation at the annual AAEA meetings,
Providence, RI, July 2005

Abstract

Water quality has implications for the health of our ecosystem and the welfare of our population. Agriculture is one of the major contributors of non-point source pollution that contaminates our nation's water supplies. Understanding how farmers substitute manure for commercial fertilizers allows us to better understand the level of nitrogen that enters the soil and can seep into our waterways. In this paper, we explore the factors that help determine farmers' substitution rates between the two types of fertilizers. Location, crop type, and time all could play important roles. We analyze USDA farm level survey data for both crop and livestock farms covering the years 1996 to 2002 to create substitution rate estimates used on corn, soybean, and wheat fields. While the substitution rates we found did not appear to change over the time frame examined, we did find that crop type and location significantly affected the rates that farmers use. Additionally, and perhaps most importantly, the substitution rates we did find did not conform to the "perfect substitution" between N coming from commercial sources and manure used in much of the literature. This means that previous studies could have underestimated the potential level of pollution of our water by our nations' farms.
Keywords: manure, commercial fertilizers, substitution, corn, soy, wheat

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1. Introduction

Water quality is a major concern in the United States. It has implications for the welfare of our ecosystem and the health of our population. In 2000, states reported that nearly 40 percent of assessed rivers and streams did not meet water quality standards (National Water Quality Inventory 2000 Report). More recently, the Environmental Protection Agency gave the US coastal ecology and water quality a fair to poor rating and established that conditions have remained the same over the years spanning 1990 to 2000 (National Coastal Condition Report II, 2004).

Agriculture is one of the main contributors to nonpoint source pollution (pollution that does not originate from a single source, or point). According to a 1996 report by the Natural Resources Conservation Service titled "Water Quality", agriculture contributes sixty percent of the impaired river miles. Among other issues, water quality concerns include the runoff from fertilizers (both organic and inorganic) and other chemicals.

Incentives and restrictions have been introduced in an attempt to decrease the potential for water contamination. Recognition of the impact of agriculture on the quality of water has prompted ever larger increases in conservation/water quality funding in the 1985, 1990, 1996, and 2002 Farm Acts. The Conservation Reserve Program, the Environmental Quality Incentives Program, and the newly funded Conservation Security Program are examples of United States Department of Agriculture (USDA) programs aimed, at least in part, to help to address water quality issues. These programs attempt to induce voluntary farm operator participation and thereby diminish the buildup of excess nutrient levels that contribute to the contamination of our water supply.

Recent large structural changes have also taken place in the agriculture industry. The heavy consolidation has led to the development of large animal feeding operations (AFOs). These farms produce high levels of manure which require disposal. If simply spread on the land without reasonable attention to the agronomic needs of the crops, the nutrients in the manure could exceed the crop requirements. Excess nutrients could then leach or runoff into the water supplies, lowering its overall quality. As a result, Congress has passed legislation aimed at concentrated AFOs that require the adoption of Comprehensive Nutrient Management Plans (CNMPs) for operations of a certain size, including with penalties if not appropriately implemented.

CAFOs with less land than required to correctly utilize the manure they produce have several options including purchasing or renting more land so that they can properly use or dispose of the manure; selling (or giving away) their manure to other farms (e.g. crop farms) through a manure application agreement; or producing fewer animals. Iowa, for example, has developed markets for manure whereby a typical manure arrangement includes a ten year easement and a price of $20 per acre (compared to the approximate cost of $40-$50 per acre for a comparable amount of commercial fertilizers).[1]

However, regulations do not limit the total application of nutrients (from both organic and inorganic sources) on farms that purchase manure.[2] Since manure prices lie substantially below the prices of inorganic fertilizers, demand for fertilizers may actually increase for these farms, potentially causing an over-application of nutrients. If so, establishing manure markets could undermine the effectiveness of the regulations.

[1] These details come from a conversation we held with Kelvin Leibold from the Iowa State University Extension Service, Hardin County, IA.
[2] Unless, for some reason, a livestock farm with a manure management plan decides to purchase manure.

The key to understanding the potential for water pollution lies in accurately measuring the production of excess nutrients. This, in turn, relies heavily upon understanding the use of both organic and inorganic fertilizers in crop cultivation. Excess nutrient accumulation has been studied extensively by Kellogg, et al. (2000). This seminal piece provides the foundation for calculating the production of nitrogen (N) and phosphorus (P) coming from livestock (in the form of manure) and understanding the capacity of the cropland and pastureland to assimilate the N and P for productive purposes. The excess not used in crop production (or otherwise assimilated by the land) then becomes potential pollution that can enter the nation's waters. Meyer, et al. (2003) built upon Kellogg et al.'s approach through the study of the costs associated with the development and implementation of the CNMPs. In order to do so, Meyer, et al. (2003) go into great detail concerning the calculation of nutrient production from farms utilizing various types of manure storage facilities (e.g. pits, slurries, basins, ponds, lagoons, manure pack, etc.). Different storage techniques create different nutrient losses of the manure (due to volatilization, for example), resulting in different amounts of nutrients applied when spreading the manure on crop or pastureland. By categorizing farms by their manure storage facilities, Meyer, et al. (2003) can more accurately provide information concerning the potential nutrient accumulation and costs of implementing CNMPs.

While Meyer, et al. (2003) focuses primarily on the costs of implementing CNMPs for various farm types, Kellogg, et al. (2000) attempts to assess the implications for the potential for pollution. The main drawback to this aspect of their study is that they do not account for inorganic fertilizers. While their study is aimed at understanding the potential for pollution coming from the accumulation of excess nutrients due to animal production, they cannot fully calculate the potential for pollution since they ignore the use of commercial fertilizers.

Other studies and policy analyses examining the accumulation of excess nutrients similarly ignore the use of inorganic (or commercial) fertilizers, or contain an implicit (and sometimes explicit) assumption of perfect substitution between inorganic and organic fertilizers due to the way regulations are written that incorporate 1:1 substitution rates (e.g. Ribaudo, et al., 2004). Previous work on manure use tends to focus on whether manure can substitute for commercial fertilizers and, if it can, how much manure should be used (e.g. Peterson, et al., 1991; Sahs and Lesoing, 1985). Additional work examines the amount of land required to use the nutrients coming from manure, ignoring any commercial fertilizer use, again due to the way regulations are written (e.g. Gollehon, et al., 2001). Kaplan, et al. (2004) examine the implications of constraining the land application of manure and Johannson and Kaplan (2004) examine how meeting nutrient standards could lead to potentially large changes in returns to agricultural production and water quality. Using simulation models, they suggest that production would decrease, prices would increase (again assuming a perfect substitution between manure nutrients and commercial fertilizer nutrients due to the way regulations are written), and the amount of nutrients leaching into the nation's water supply would decrease. Related but tangential work has examined the N, P, and K (potassium) uptake rates between plots of land using compost versus fertilized and unfertilized plots on irrigated wheat (Bar-Tal, 2004). Other work has explored the effect of substitution on yield rates, nutrients, and soil fertility in developing countries such as India (Yaduvanshi, 2003) and Nigeria (Adediron, et al., 2004). These types of studies tend to be normative in nature. They attempt to find the optimal application rates of organic and inorganic fertilizers.

However, little has been done on *actual* manure and commercial fertilizer use practices. When manure can be viewed as a "bad," or an output that cannot be freely disposed of, we need to know what the actual substitution practices are in order to understand the environmental implications. If we find that substitution rates are lower than those assumed in the literature (to conform to regulations), it would appear that previous results would have underestimated the amount of nutrients left in the soil. This could increase our estimates of the level of pollutants reaching our waterways, exacerbating the water quality problems that face our nation. Additionally, if regulations are based upon a 1:1 substitution rate that farmers do not adopt (for agronomic reasons or otherwise), the regulations could have unintended consequences (such as preventing the proper distribution of manure on fields for disposal, which could lead to greater likelihoods of spillage, overflow of lagoons, etc.) which could further exacerbate the potential for pollution.

A priori, organic and inorganic fertilizers do not appear to be perfect substitutes due to measurement costs, transportation costs, and distribution costs, amongst other reasons. Measurement issues arise since the precise levels of nutrients cannot be known with certainty due to losses (volatilization, etc.). In addition, different species produce manure with different nutrient balances, making measurement difficult. Transportation costs for manure are also high, both from the waste receptacle to the field and in terms of compacting the field during application. Distribution costs include the cost of air pollution and the associated potential for lawsuits and/or fines. Moreover, the ratio of nutrients in manure are not the same as the ratio taken up by plants, either requiring a suboptimal distribution of nutrients or combining both organic and inorganic fertilizers to achieve desired nutrient levels (Rasnake, 1996).

In general, therefore, we would not expect to find a 1:1 substitution between the two types of fertilizers. We also expect that substitution rates might differ depending on soil type and crop needs. Additionally, as consolidation increased, substitution might have become more prevalent and better methods for decreasing the costs of substituting the two types of fertilizers might have developed, creating time trends in substitution rates.

In this paper, we explore the factors that help determine farmers' substitution rates between manure and commercial fertilizers. Location, crop type, and time all could play important roles to determine these rates. Finally, we explore whether or not farmers tend to substitute manure for commercial fertilizers to satisfy the N requirements of the crop.

2. Methodology

We wish to explore the connection between the application rates of organic and inorganic fertilizers by using a cross-sectional approach and regressing the level of commercial fertilizer application on the level of manure application along with state fixed effects, the size of the operation, and whether or not the farm produced livestock. Let Y_{ic} represent the amount of nutrients (N) coming from commercial fertilizer that farm *i* spreads on each acre of crop *c*. Let Y_{ic} be a function of a set of factors X_{ic} that characterize the farm and the producer that influence the propensity to alter the level of commercial fertilizers used on the cropland. We posit that the level of nutrients from commercial fertilizer used will be influenced by the amount of nutrients from manure spread on the farm (which we expect, for the most part, to be a function of the level of manure produced on the farm from livestock). Therefore let M_{ic} denote the level of nutrients from manure applied to each acre of crop *c* on farm *i*. The model then looks like the following:

$$Y_{ic} = \alpha + \beta X_{ic} + \gamma M_{ic} + \varepsilon$$

γ should then represent the coefficient of substitution of manure for commercial fertilizer. The potential for endogeneity bias exists since the application of manure represents a choice variable. For the sake of the current study, however, we assume that the application of manure comes from the level of manure produced on the farm, which comes from the number, and type, of animals produced on the farm. We can control for the type of livestock present on the farm and the size of the farm. This methodology should allow us to achieve estimates of the degree to which farmers actually substitute the nutrients in manure for those in commercial fertilizers.

3. Data

To aid us in our estimation, we need information concerning the rates at which farmers spread commercial fertilizers (in the form of N and P) and the rates at which they spread the manure produced on the farm. We focus on three crops in particular: corn, soybeans, and wheat. These are three of the most commonly produced crops in the country and, as a result, also have the most information available for them. These also represent crops with widely different agronomic needs, which will help us to explore whether or not the agronomic needs play a role in the substitution rates farm operators use.

Economic Research Service (ERS) and the National Agricultural Statistics Service (NASS) combine their efforts to produce a survey and collect the data from thousands of farmers every year, constructing a dataset called the Agricultural Resource Management Survey (ARMS). This survey is used to collect detailed information concerning the production practices of various types of farms from all over the United States. This information includes actual production practices, the costs of production, and income information, amongst other data. The survey is conducted in three main phases. Phase I consists of identifying producers that qualify for inclusion on the survey. Phase II consists of a series of commodity surveys conducted to obtain information on production inputs, management practices, and commodity cost of production, performed at the field level. The survey is designed to represent all the US farmers of a particular commodity (e.g. in 2001, farmers with corn were surveyed, with the intention of having the survey results reflect all farmers in the US who grow corn). Phase III collects more detailed information about the farm income and expenditures as well as other aspects of the farm business and the operator's household, but does not contain as detailed information on the management practices. The resulting sample of farmers is not random. Instead, operations are selected to gain a representative sample of farms. Weights are then assigned to each observation in order to expand the result from the sample to the entire population of farms in the United States.

The particular two datasets that we employ in this paper are the Crop Production Practices (CPP) and the Enterprise Cost of Production (COP) datasets. The CPP datasets are from the ARMS Phase II surveys and contain detailed information about field level production practices for each crop. Data exist for each crop (corn, soybeans, and winter wheat) for each year from 1996 through 2000. In 2001, the surveys were modified to gather data from only a single crop rather than from all the crops previously surveyed. Therefore in 2001, data only exist for corn and in 2002, data exist only for soybeans.

Each year contains approximately two to three thousand observations in approximately 20 states for each crop. Due to the relatively small number of observations per state, we pool the years of 1996 through 1998 together and the years 1999 through 2002 together, creating six CPP datasets: two for each crop.[3]

[3] The states surveyed that grow corn include Colorado, Georgia, Indiana, Illinois, Iowa, Kansas, Kentucky, Michigan, Minnesota, Missouri, Nebraska, New York, North Carolina, North Dakota, Ohio, Pennsylvania, South

The CPP datasets contain information concerning the amount of manure spread on the field, the main source of manure (whether from hogs, dairy, beef, etc.), and the number of acres manure was spread on. Using the methods described in Kellogg, et al. (2000), we can calculate the nutrient content of the manure, after losses (due to volatilization, etc.). This allows us to construct the N and P application per acre from manure that we can use in the regression analyses.

While the CPP data contain detailed information allowing the calculation of the amount of N applied per acre from commercial fertilizers and manure, they do not contain any information on the characteristics of the operator, the farm operation, or the household in general. This could lead to omitted variable biases if we cannot control for other aspects of the operation that potentially play an important role in determining the substitution rate between organic and inorganic fertilizers. We therefore also utilize the COP datasets which comes from the ARMS Phase II and Phase III surveys. It is much more limited in scope due to the burden it places on farm operators to respond to two surveys (one for the field practices and one for the overall farm operation). However, it does contain explicit amounts of N placed on the field from both organic and inorganic sources.[4]

Table 1 contains descriptive information including the name of the variable, a brief description, and its overall mean for each of the two datasets. The first two variables are the dependent variables for the regressions, denoting the amount of N and P per acre from commercial fertilizer spread on the crop. The next two variables are the main variables of

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Carolina, South Dakota, Texas, and Wisconsin. The states surveyed that produce soybeans include Arkansas, Delaware, Indiana, Illinois, Iowa, Kansas, Kentucky, Louisiana, Maryland, Michigan, Minnesota, Mississippi, Missouri, Nebraska, North Carolina, North Dakota, Ohio, Pennsylvania, South Dakota, Tennessee, Virginia, and Wisconsin. The states surveyed that grow wheat include Arkansas, California, Colorado, Georgia, Idaho, Indiana, Illinois, Kansas, Kentucky, Louisiana, Mississippi, Missouri, Montana, Nebraska, North Carolina, Ohio, Oklahoma, Oregon, Pennsylvania, South Dakota, Texas, and Washington.

interest - the amount of N and P per acre from manure spread on the crop. The means of these first four variables are contingent upon the operator actually spreading the manure. For example, those operators spreading N from commercial fertilizers on corn in the CPP dataset put an average of 118.44 pounds of N per acre. This is close to the estimate from the COP dataset where those farmers spreading N from commercial fertilizers put an average of 112.88 pounds of N per acre on their corn. From perusing the table, it is apparent that the CPP and COP datasets have very similar means for the variables.

We would expect the amount of N from manure per acre spread on the farm to be negatively correlated with the amount of N from commercial fertilizers used.[5] A value of (-1) correlation would imply that N from manure perfectly substitutes for N from commercial fertilizers (a common assumption currently in the literature as noted earlier), while a value lying in (0, -1) would imply imperfect substitution.[6]

The rest of the variables in table 1 represent control variables that we use in the regression analyses. To control for farm size, we use the number of acres planted of the crop. This is not a perfect control, but the best we can do for the CPP dataset. The COP dataset, however, includes information on the amount of production on the farm. VPRODTOT captures the value of production that took place on the farm, making it a better control for the farm size. We don't have any prior expectations for the sign or magnitude of this variable. As mentioned earlier, our analyses effectively aim to understand the application rate of commercial fertilizers, since we regress the application rate of commercial fertilizers on the application rate of manure

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[4] Farmers producing corn were surveyed in 1996 and in 2001. Operators growing soybeans were surveyed in 1997 and in 2002. Farmers producing wheat were surveyed in 1998.

[5] For simplicity, we will restrict our discussion to the operators' use of N. However, the same arguments apply to their use of P.

[6] Imperfect substitution means that one pound of manure replaces less than one pound of commercial fertilizer and would lead to an increase in the total amount of nutrients placed on the field.

and other controls. If farms with higher VPRODTOT generate more manure, they would need to get rid of more manure, meaning they might place less commercial fertilizers on the crops, giving the farm size variable a negative coefficient. Alternatively, since they are larger and face larger losses if they improperly fertilize, they might have a better understanding of the agronomic needs of the crops, which could lead to higher levels of commercial fertilizers used.

To control for whether or not the farmer tested the soil for its chemical content, we included a dummy variable. This proxies for how committed the operator is to understanding the agronomic needs of the crop.

The population density variable controls for how heavily populated the area is where the operator farms. Higher levels of population can mean many things. Among others, it could have impacts on the use of manure. Odors are more likely to instigate actions that could harm the well-being of the operators in heavily populated areas. This could lead to a lower use of manure in these areas as a substitute. Alternatively, more heavily populated areas have a higher demand for land, increasing property values. This might cause farms to have fewer acres to operate on. If farms have livestock, this means that they would produce a higher ratio of manure nutrients to acres, which they would have to dispose of on their land, which could lead to higher rates of manure spreading.

The aforementioned variables all exist in both the CPP and COP datasets. However, the CPP datasets do not consistently contain any information on the attributes of the operator, the operator's household, or the operation itself. Additional variables that could alter the substitution rates of manure nutrients for commercial fertilizer nutrients include those that characterize the operator. Age, experience, education, and occupation (is the operator a full time farmer versus a hired manager? Does the operator have some other full time occupation and farms on the side? Or is the operator retired?) all could alter the production practices used on the farm. In the analyses using the COP dataset, we include these variables to see if the results remain robust to the farmers' characteristics.

Operators have several choices when growing their crops. They can choose to not fertilize, or they can provide nutrients for their crops using commercial fertilizers, manure, soybean credits, alfalfa credits, or some combination of the four. Table 2 shows how many farms from each dataset (CPP and COP) fall into each category. This gives an idea of what the fertilizer patterns look like, as well as allowing an exploration of how similar the two datasets are. Entries for each dataset exist for each crop in each year. While CPP datasets contain other years' worth of data, we restricted the table to only include those years that coincide with the COP datasets, to allow for closer comparisons. Numbers in the table represent expanded values of farms based on the actual number of observations and the appropriate weights supplied.

With the exception of the percent of farms spreading manure on soybean fields in 2002 and corn fields in 1996, and the percent of farms spreading both manure and commercial fertilizers on corn fields in 1996, the percentages for the two datasets are remarkably similar for each crop and year. Not surprisingly, a much smaller percentage of farms spread any types of fertilizers on soybean crops than on corn or wheat crops (since soybeans fix nutrients into the soil, and therefore do not require the provision of these nutrients for growth).

4. Results

Several sets of regressions have been run on the data to check for robustness. In the first set of regressions, we used CPP data. We lumped all states and years together to get estimates of the substitution between manure and commercial fertilizers for corn, soybeans, and wheat. As suggested previously, the regression itself attempts to explain changes in the amount of commercial fertilizer used. While the control variables are important to properly assess the impact of manure spreading on commercial fertilizer use, we focus our attention on the coefficient of the manure variable and are not interested in the coefficients of the control variables. For this first set of regressions, we did use state fixed effects to control for location and year fixed effects (lumping years into two periods: yr1 = 1996-1998 and yr2 = 1999-2002). We also included the size of the farm (planted acres of the crop), whether or not the farmer used a soil test, and the population density of the area within which the operation existed. Table 3 contains the results.

All three crops had negative and strongly significant (at the 1% level) coefficients of substitution. The coefficients did differ dramatically across all three, and perhaps most importantly, none of the coefficients of substitution were close to 1. This implies that the type of crop does matter as to whether or not farmers are willing to substitute organic fertilizers for inorganic fertilizers. Additionally, it implies that operators do not view the two types of fertilizers as perfect substitutes. The R^2 for the corn and wheat regressions are substantially higher than those for the soybean regression. This makes sense since, as mentioned earlier, soybeans do not require N to grow. It is likely that a lot of the manure spread on soybeans is simply an attempt to get rid of the manure rather than trying to provide the agronomic needs of the crop.

We then ran regressions for each crop by time period, to see whether or not time trends existed for substitution rates, again using the CPP data. Using the same set of control variables, reran the regressions, the results of which are shown in table 4. While all the coefficients on the manure variable remained significant and negative (implying substitution), there does not appear to be any time trends. The coefficients appear to be very similar for the time periods 1996-1998 and 1999-2002. As before, the R^2 for the corn and wheat regressions are substantially higher than those for the soybean regression.

The next step was to see whether we could use the CPP data to get substitution estimates for each state. Location could be important as different soils have different characteristics and could allow for varying substitution rates to grow the crops successfully. We ran separate regressions for each state to obtain our estimates. Again, the same sets of controls were used. Due to the large number of states and the difficulty of presenting the material in a concise fashion, we only report the substitution coefficients and the number of observations for each regression. Additionally, due to space constraints, we represent the significance of the coefficients in the standard manner (where *** represents significance at the 1% level, etc.) but omit the standard errors. Full results of all the regressions run are available upon request. Results lie in table 5.

The first thing to note about the coefficients for each state is that they are not the same: it appears that location matters. According to Camberato, et al., only 30-80% of organic N from manure is available in the first cropping season due to degradation rates of manure. These rates vary heavily and depend upon moisture content, oxygen concentration, and temperature. The degradation rates could help explain why substitution rates do not approach (-1).

Many of the coefficients for corn are statistically significantly different from zero and all of them are negative (implying substitution). Only Missouri has a coefficient of substitution greater than 1 (i.e. a pound of N from manure replaces more than a pound of N from commercial fertilizers). This result is somewhat unexpected. However, all the other coefficients of substitution are less than 1. While Indiana, South Dakota, and Texas have coefficients close to 1, most of the statistically significant coefficients are significantly smaller than 1, ranging from -0.11 in Wisconsin to -0.47 in Minnesota. Several states have coefficients that are not statistically significantly different from zero.

Soybean operators have a much different story to tell. Most of the coefficients are negative, but not all of them are. This implies that some operators treat manure as a complement to commercial fertilizers. However, none of the positive coefficients are statistically significant. Only a handful of states have substitution coefficients that are statistically significant, and these rates tend to be much smaller than the substitution rates used for corn crops. Wheat follows a similar pattern to soybeans, with very few statistically significant coefficients. Substitution rates appear to be higher for wheat than for soybeans (with many rates higher than 1). However, the main result to note is that the coefficients appear to be different across crops and location. The results for soybeans and wheat could be driven, at least in part, due to the small numbers of operations that spread manure. Less than 7% of farms spread manure for either crop. Less than 30% of farms growing soybeans used commercial fertilizers, while less than 70% of operations producing wheat spread commercial fertilizers.

The next step was to compare the results generated by CPP data with those of COP data. We chose operators who grew corn in 2001. We first took the CPP data and restricted them to only those observations in 2001 and ran the CPP regression outlined previously. We then took the COP data and ran three separate regressions. The first used the same variables as the CPP regression to get as close a comparison between the two datasets as possible. The second regression substituted VPRODTOT (the total value of production) for the acres of the crop (corn in this case) planted on the farm. The third added in all the operator characteristic variables (education, occupation, age, and experience). Results lie in table 6.

It is clear that the CPP and COP datasets do not contain the same samples of individuals. In looking at the CPP regression and the first COP regression, while similar, the results are not identical. Comparing the main variable of interest, the substitution rate, it is statistically different for the two datasets, although it does retain its sign and level of significance. The COP dataset produces a lower estimate of the substitution rate. For soybeans and wheat, these differences are even more pronounced.[7] However, we are interested in understanding whether or not farmers' characteristics altered the results. By comparing the results of the three COP regressions, it is clear that the operators' characteristics do not alter the coefficient on the manure/acre variable. In other words, the size and significance of the substitution rate remains robust to the inclusion of the operator's characteristics.

To further explore the COP data, we ran regressions for all the crops in all the years using the third COP specification in table 6. Clearly the results differ from those of the CPP data sets (table 7). Although the two datasets are not directly comparable (other than table 6), the substitution coefficients for the 1996 corn, the 2002 soybeans, and the 1998 wheat findings are not statistically different from zero. While all the coefficients are negative, implying that manure substitutes for commercial fertilizers, the lack of statistical significance could imply that in general the rates are close to zero. In fact, the coefficients for soybeans and wheat are very close to zero while those of corn are substantially higher.

One possibility is that the COP datasets contain fewer individuals who use fertilizers of any sort. We therefore run another set of regressions including only those operators who place either commercial fertilizers and/or manure on their fields, excluding those who do not fertilize in any fashion (table 8). Results show a much stronger substitution rate for all the crops. Wheat, however, remains statistically insignificant. However, both corn and soybeans for all the years

[7] For brevity, we did not include all the crop and year regression comparisons. They are available upon request.

we have data for are significant and negative. Again, none of the substitution rates comes close to approaching a value of (-1) (i.e. perfect substitution). Substitution rates range from -0.18 for soybeans in 1997 to -0.37 for corn. Again, in the time frame we are looking at, substitution rates do not appear to change over time, but do appear to matter for the type of crop.

5. Conclusions

Water quality is a major concern in the United States. Agriculture remains one of the main non-point sources of pollution and attempts to improve our coastal ecology and water quality have made little or no headway in the last ten years despite incentives put in place by Congress and the formation and passage of new laws to help curb pollution by CAFOs (National Coastal Condition Report II, 2004). The key to improving our water nation's water supply lies in understanding the sources of pollution and being able to accurately measure the contaminants.

Previous studies on the potential for pollution from fertilizers in agriculture have either assumed away commercial fertilizer use or assumed that manure made a perfect substitute for commercial fertilizers to explore the effects of regulations that are written with this assumption. We argue that manure is not a perfect substitute and that using the assumption of perfect substitution could bias the measurement results. This could even lead to unintended consequences of regulations if farmers were required to use this unrealistic substitution rate.

This study examines the potential sources of pollution from farms engaging in the production of corn, soybeans, and wheat over the years spanning 1996 through 2002. We attempt to measure the accumulation of nutrients (in particular, N) and their use on the fields and gauge to what extent manure is substituted for commercial fertilizers. We use two datasets from ARMS: the CPP and COP datasets. The CPP only contains information on the use of manure and commercial fertilizers while the COP datasets also contain data on the household, operator, and farm characteristics.

We find that substitution rates do appear to vary across crops and location. Degradation rates of manure might help to explain these findings. They do not, however, appear to vary over the time frame explored. Additionally, and perhaps most importantly, the substitution rates we were not close to -1 (i.e. perfect substitutes) for N. In other words, farmers did not use N from manure as a perfect substitute for N from commercial fertilizers. If this is the case, previous studies may have underestimated the amount of nutrients placed on the fields and hence the potential for pollution accruing from agricultural practices. The degree to which the "underestimation" occurred would be a function of both the crop and the location.

The last question then is: which data set do we prefer? COP contains Phase II and Phase III survey data, which means it has a severely restricted number of observations compared to the CPP data. The inclusion of the farm and operator characteristics do not appear to provide a better specification of the substitution rate, therefore we place more confidence in the findings of the CPP data than the COP data.

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Table 1. Descriptive Statistics

Variable Names	Variable Description	CPP Dataset CORN	CPP Dataset SOYBEANS	CPP Dataset WHEAT	COP Dataset CORN	COP Dataset SOYBEANS	COP Dataset WHEAT
cf_n_acre*	N / acre: commercial fert.	118.44	22.09	72.93	112.88	20.69	70.00
cf_p_acre*	P / acre: commercial fert.	54.61	48.46	42.04	54.02	46.84	41.01
man_n_acre*	N / acre: manure	42.52	29.18	23.76	51.02	36.65	31.39
man_p_acre*	P / acre: manure	19.40	16.77	13.87	17.44	14.31	12.45
soiltest	Was a soil test performed?	0.16	0.24	0.23	0.25	0.18	0.21
popdense	Population density	120.75	118.41	75.70	116.58	106.72	76.74
aplfarm	Farm planted acres	306.95	460.44	490.63	197.58	245.33	293.59
vprodtot	Total value produced	--	--	--	196,761	216,887	161,150
age	Age	--	--	--	51.8	52.5	54.07
lths	Edu: less than high school	--	--	--	0.12	0.07	0.09
hs	Edu: high school	--	--	--	0.48	0.50	0.47
somecol	Edu: some college	--	--	--	0.25	0.27	0.24
colplus	Edu: college degree or more	--	--	--	0.15	0.06	0.20
occfr	Occ: Farmer	--	--	--	0.772	0.70	0.78
occhm	Occ: Hired Mgr	--	--	--	0.003	0.07	0.01
occoth	Occ: Other	--	--	--	0.181	0.23	0.16
occret	Occ: Retired	--	--	--	0.044	0.00	0.05
experience	Years managing a farm operation	--	--	--	30.7	30.3	28.8
	N	6,407	5,106	1,807	2,811	3,379	1,457

*Conditional upon application

-- denotes not available in CPP dataset.

Table 2. CPP and COP: Number of Farms

	Dataset	Farms spreading c. fert. (N)	(%)	Farms spreading c. fert. (P)	(%)	Farms spreading manure	(%)	Farms spreading both	(%)	N (actual)	N (expanded)
CORN	CPP	1,678,017	96.6	1,485,898	85.5	338,846	19.5	305,493	17.6	3,421	1,737,193
1996	COP	347,028	95.6	316,215	87.1	18,779	5.2	17,022	4.7	950	363,052
CORN	CPP	208,871	94.4	176,770	79.9	53,279	24.1	47,704	21.6	2,986	221,259
2001	COP	338,414	94.0	286,406	79.6	97,357	27.1	87,648	24.4	1,861	359,842
SOYBEANS	CPP	391,343	23.6	529,110	31.9	117,666	7.0	33,069	2.0	2,580	1,659,964
1997	COP	69,928	23.8	86,995	29.6	31,300	10.6	6,748	2.3	1,444	293,928
SOYBEANS	CPP	38,384	21.7	47,488	26.9	14,029	7.9	2,201	1.2	2,526	176,824
2002	COP	61,949	22.1	76,183	27.1	7,222	2.6	623	0.2	1,935	280,775
WHEAT	CPP	542,285	90.2	418,798	69.7	26,769	4.5	21,796	3.6	1,807	601,021
1998	COP	170,360	87.4	128,872	66.1	11,088	5.7	9,326	4.8	1,457	194,847

Table 3. CPP Regressions All Farms (Dep. Var. = Comm. Fert. (N)/Acre)

	CORN	**SOYBEANS**	**WHEAT**
Intercept	71.45***	5.40***	57.88***
	(1.81)	(0.93)	(4.76)
Manure (N)_Acre	-0.24***	-0.03***	-0.38***
	(0.02)	(0.01)	(0.08)
Soil Test	7.84***	2.14***	14.41***
	(1.35)	(0.32)	(1.74)
Population Density	0.006	0.004***	0.01
	(0.005)	(0.001)	(0.01)
Farm Planted Acres	0.03***	-0.00007	0.004***
	(0.001)	(0.0002)	(0.001)
State Fixed Effects (FE)	Y	Y	Y
YR FE	Y	Y	Y
R^2	0.23	0.05	0.20
N	13,825	12,491	3,533

*** Indicates significance at the 1% level
** Indicates significance at the 5% level
* Indicates significance at the 10% level
Values in parentheses are standard errors.

Table 4. CPP Regressions by YR (Dep. Var. = Comm. Fert. (N)/Acre)

	CORN		**SOYBEANS**		**WHEAT**	
	1996-1998	1999-2002	1996-1998	1999-2002	1996-1998	1999-2002
Intercept	65.99***	76.69***	5.53***	5.39***	76.07***	48.12***
	(2.93)	(2.16)	(1.74)	(1.01)	(7.08)	(6.42)
Manure (N)_Acre	-0.23***	-0.25***	-0.03*	-0.03**	-0.32***	-0.42***
	(0.03)	(0.02)	(0.02)	(0.01)	(0.12)	(0.11)
Soil Test	8.36***	7.13***	2.28***	1.97***	7.84***	21.95***
	(2.13)	(1.75)	(0.53)	(0.40)	(2.30)	(2.68)
Population Density	0.01*	0.001	0.005*	0.004***	0.006	0.03*
	(0.008)	(0.007)	(0.003)	(0.002)	(0.01)	(0.02)
Farm Planted Acres	0.03***	0.03***	0.0003	-0.0004*	0.003	0.005***
	(0.002)	(0.002)	(0.0005)	(0.0003)	(0.002)	(0.002)
State FE	Y		Y		Y	
R^2	0.23	0.25	0.06	0.04	0.19	0.24
N	5,903	7,921	4,919	7,571	1,806	1,726

*** Indicates significance at the 1% level
** Indicates significance at the 5% level
* Indicates significance at the 10% level
Values in parentheses are standard errors.

Table 5. CPP Substitution Coefficients by State (Dep. Var. = Comm. Fert. (N)/Acre)

State	CORN		SOYBEANS		WHEAT	
	Manure/Acre	N	Manure/Acre	N	Manure/Acre	N
AK	--	--	0.28	681	-1.56	81
CA	--	--	--	--	-0.98*	34
CO	-0.27**	382	--	--	-0.19	176
DE	--	--	-0.16***	148	--	--
GA	-0.68	71	--	--	-1.60	69
ID	--	--	--	--	-2.31	214
IL	-0.46**	1215	-0.01	1203	0.10	192
IN	-0.88***	982	-0.03	751	-0.57**	176
IA	-0.40***	1785	-0.04	1035	--	--
KS	-0.43**	688	-0.25	556	-0.24	529
KY	-0.14	498	0.01	468	-0.09	85
MD	--	--	0.06	81	--	--
MI	-0.25***	559	-0.06	420	--	--
MN	-0.47***	1176	-0.01	895	--	--
MS	--	--	-0.17	827	--	--
MO	-1.39***	743	0.01	724	-0.28	124
MT	--	--	--	--	-0.10	159
NE	-0.16	1064	-0.02	813	-5.66***	119
NY	-0.11*	177	--	--	--	--
NC	0.28	467	-0.07	472	-0.32	142
ND	-0.31***	188	0.59	203	--	--
OH	-0.38***	936	-0.03	759	-0.23	155
OK	--	--	--	--	-5.59	300
OR	--	--	--	--	-0.69	141
PA	-0.27***	536	-0.08***	321	--	--
SD	-0.74***	812	-0.01	574	-0.33	143
TN	--	--	-0.12*	530	--	--
TX	-0.97**	508	--	--	-1.18	319
VA	--	--	-0.03	70	--	--
WA	--	--	--	--	-1.11	208
WI	-0.11***	965	-0.03*	257	--	--

-- represents no data for that state
*** indicates significance at the 1% level
** indicates significance at the 5% level
* indicates significance at the 10% level
For space issues, the standard errors were not reported in this table. They are available upon request.

Table 6. Comparison of 2001 COP and CPP Regressions

Variable	CPP Regression		COP Regression 1		COP Regression 2		COP Regression 3	
	Coefficient	Std. Error	Coefficient	Std. Error	Coefficient	Std. Error	Coefficient	Std. Error
Intercept	91.21***	4.40	87.47***	5.41	91.70***	5.46	98.82***	13.53
Manure/Acre	-0.47***	0.04	-0.34***	0.04	-0.37***	0.04	-0.35***	0.04
Soil Test	8.97***	2.72	2.56	3.41	4.64	3.45	4.65	3.45
Pop. Density	0.01	0.01	-0.01	0.02	-0.01	0.02	-0.02	0.02
Farm Planted Acres	0.02***	0.002	0.03***	0.004	--	--	--	--
VPRODTOT	--	--	--	--	5.5E-6*	2.8E-6	2.6E-6	2.9E-6
Occ = Farmer	--	--	--	--	--	--	15.42*	8.75
Occ. = Hired Mgr	--	--	--	--	--	--	-7.93	26.13
Occ. = Other	--	--	--	--	--	--	4.42	9.26
Age: 30-40	--	--	--	--	--	--	-8.83	9.27
Age: 40-50	--	--	--	--	--	--	-11.23	9.00
Age: 50-60	--	--	--	--	--	--	-18.98**	9.00
Age: 60-70	--	--	--	--	--	--	-17.67*	9.31
Age: 70+	--	--	--	--	--	--	-8.93	9.93
Edu: LTHS	--	--	--	--	--	--	-27.07***	5.37
Edu: HS	--	--	--	--	--	--	-5.53	4.01
Edu: SCOL	--	--	--	--	--	--	-8.45*	4.46
Experience	--	--	--	--	--	--	0.01	0.01
State FE	Y		Y		Y		Y	
R^2	0.23		0.22		0.19		0.22	
N	2975		1855		1855		1843	

Table 7. COP Regressions: All Farms

Variable	CORN				SOYBEANS				WHEAT	
	1996		2001		1997		2002		1998	
	Coefficient	Std. Error	Coefficient	Std. Error	Coefficient	Std. Error	Coefficient	Std. Error	Coefficient	Std. Error
Intercept	85.11***	17.06	98.82***	13.53	7.19**	3.19	5.29	4.63	63.97***	11.60
Manure/Acre	-0.30	0.20	-0.35***	0.04	-0.06**	0.03	-0.03	0.03	-0.02	0.08
Soil Test	16.58***	4.07	4.65	3.45	1.86*	0.97	1.77**	0.79	11.34***	2.56
Pop. Density	-0.01	0.02	-0.02	0.02	-0.004	0.005	0.001	0.002	0.01	0.01
VPRODTOT	2.3E-5***	6.5E-6	--	--	-6.7E-7	1.3E-6	-2.1E-7	3.1E-7	2.1E-5***	3.3E-6
Occ = Farmer	-38.10***	8.86	2.6E-6	2.9E-6	-0.16	1.07	-1.50	4.20	9.10*	5.05
Occ. = Hired Mgr	-15.32	31.02	15.42*	8.75	3.02	2.04	-1.41	4.30	32.42***	10.11
Occ. = Other	-44.84***	9.87	-7.93	26.13	--	--	-1.29	4.22	8.81	5.56
Age: 30-40	-15.43	12.74	4.42	9.26	1.19	2.55	1.70	1.63	-2.40	7.92
Age: 40-50	-20.10	12.97	-8.83	9.27	0.86	2.56	0.78	1.54	-1.62	7.86
Age: 50-60	-10.37	13.92	-11.23	9.00	3.73	2.70	1.65	1.54	1.74	8.21
Age: 60-70	-26.61*	15.23	-18.98**	9.00	3.22	2.99	0.64	1.60	-1.18	8.59
Age: 70+	-21.11	17.44	-17.67*	9.31	1.96	3.15	-0.23	1.71	-6.23	9.56
Edu: LTHS	-7.16	7.53	-8.93	9.93	-1.39	1.99	2.40*	1.28	1.76	4.33
Edu: HS	-2.88	5.39	-27.07***	5.37	-0.33	1.31	0.21	0.67	1.44	2.86
Edu: SCOL	1.34	5.81	-5.53	4.01	1.35	1.38	-0.44	0.76	3.55	3.01
Experience	0.20	0.24	-8.45*	4.46	-0.02	0.05	-0.002	0.002	-0.07	0.12
State FE	Y		Y		Y		Y		Y	
R^2	0.42		0.22		0.09		0.13		0.27	
N	937		1843		1427		1919		1445	

-- means that this category represents the omitted category. COP data from 1997 Soybeans had no instances of retired farmers.

Table 8. COP Regressions: Operations Applying Commercial Fertilizers and/or Manure

Variable	CORN 1996 Coefficient	CORN 1996 Std. Error	CORN 2001 Coefficient	CORN 2001 Std. Error	SOYBEANS 1997 Coefficient	SOYBEANS 1997 Std. Error	SOYBEANS 2002 Coefficient	SOYBEANS 2002 Std. Error	WHEAT 1998 Coefficient	WHEAT 1998 Std. Error
Intercept	92.72***	17.00	93.85***	12.85	10.81	8.61	12.03	10.41	64.60***	10.97
Manure/Acre	-0.37*	0.20	-0.37***	0.04	-0.18***	0.04	-0.20***	0.04	-0.06	0.07
Soil Test	12.99***	4.00	5.74*	3.34	4.10	2.49	-0.35	1.83	8.35***	2.39
Pop. Density	0.002	0.02	-0.03*	0.01	-0.01	0.01	-0.003	0.005	-0.01	0.01
VPRODTOT	2.3E-5***	6.4E-6	2.5E-6	2.7E-6	-1.8E-6	3.2E-6	-9.4E-7	2.3E-6	2.0E-5***	3.1E-6
Occ = Farmer	-35.68***	8.65	20.25**	8.32	1.96	2.83	-3.85	9.41	15.10***	4.82
Occ. = Hired Mgr	-14.77	30.10	-7.86	24.80	1.84	4.94	-6.51	9.71	31.06***	9.34
Occ. = Other	-43.39***	9.65	8.70	8.81	--	--	-3.92	9.43	15.44***	5.30
Age: 30-40	-16.96	12.71	-7.80	8.82	-3.22	8.81	12.97***	3.89	-7.23	7.64
Age: 40-50	-21.49*	12.93	-9.21	8.55	-0.45	8.81	6.66*	3.57	-6.36	7.58
Age: 50-60	-14.50	13.81	-18.12**	8.55	3.10	8.96	12.70***	3.65	-6.37	7.91
Age: 60-70	-30.08**	15.05	-13.72	8.87	3.15	9.80	10.25***	3.90	-7.05	8.30
Age: 70+	-25.18	17.19	-7.01	9.46	0.61	10.08	13.49***	4.55	-1.09	9.29
Edu: LTHS	-5.93	7.42	-24.11***	5.20	-3.55	5.39	3.36	3.41	-1.46	4.24
Edu: HS	-0.50	5.29	-3.20	3.84	-3.26	3.52	-1.25	1.95	3.65	2.74
Edu: SCOL	-0.67	5.66	-9.14**	4.27	5.33	3.74	-3.87*	2.16	5.02*	2.88
Experience	0.17	0.24	0.01	0.01	0.13	0.12	0.01	0.02	0.04	0.11
State FE	Y		Y		Y		Y		Y	
R^2	0.40		0.24		0.19		0.27		0.22	
N	912		1801		473		489		1330	