Adoption and Economic Impact of Site-Specific Technologies in U.S. Agriculture

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Abstract: A Heckman=s two-stage method is used in conjunction with data from the 1998 Agricultural Resource Management Study to estimate the likelihood of adopting a variable rate application technology (VRT) and the impact of such adoption on the per-acre costs of fertilizers and lime in cash grain production. Results highlight the importance of operator's level of human capital and attitude toward risk, along with size and location of farm in impacting VRT adoption decisions. Results also indicate no significant cost-savings attributable to VRT adoption.

Key words: Precision farming, technology adoption, probit regression, per-acre cost of fertilizer.

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Introduction

A salient characteristic of agricultural production in the U.S. is its increased dependence on fossil energy and its derivatives.[1] In the case of fertilizer usage in crop production, recent rise in natural gas prices with its attending impact on the price of nitrogen is a major concern for operators of small and large farms alike.[2] This is particularly troubling to farmers' bottom line since over 90% of the corn, cotton, potatoes, and rice acres and over 60% of the wheat acres in the U.S. receive commercial nitrogen fertilizers (Peng and Bosch). Yet another concern from applying fertilizers pertains to groundwater contamination from nitrate leaching with its associated health risks, a matter that has been raised since nitrate is the most widespread agriculturally related chemical appearing in groundwater samples (Swinton and Clark). The environmental risk of fertilizer usage has been documented by many studies where findings show that 30% to 50% of applied nitrogen may not be taken up by the crop and much of it is lost to the environment (Keeney; Peng and Bosch). Based on U.S. Geological Survey findings, nitrate-nitrogen levels in groundwater exceeded the Maximum Contaminant Limit of 10 milligram per liter limit determined safe by the Environmental Protection Agency in at least 25 percent of sampled wells in 87 counties in the U.S., mostly in the Midwest (Hatfield).

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[1] For example, a study by the United States Department of Agriculture (1997, p. 100) reports that U.S. nitrogen, phosphate, and potash use for all agricultural purposes rose from 7.5 million nutrient tons in 1960 to a high of 21.3 million tons in 1995, slightly down from its record high of 23.7 million tons in 1981.

[2] Natural gas prices have risen from a low of $2.00 per million BTU at the start of year 2000 to a high of $10 by the end of the year. Over the same time period, this increase in natural gas prices has added more than $100 per ton to the cash cost of production for anhydrous ammonia (see Doane's Agr. Report, Vol. 64, No. 6a-1. Feb. 9, 2001).

Emerging concerns about rising costs of fossil fuels and of its derivatives are apt to cause some farmers to rethink how to use some of these inputs more efficiently so as to stay competitive. This, and the fact that farmers are becoming more cognizant of society's concerns toward health and environment are factors that may encourage the adoption of certain promising technologies, especially those with potential of improving the environment while reducing cost of production. Precision farming also referred to as variable rate application farming, or site-specific management, is an example of such a promising technology. Its basic benefit is that it will enable farmers to apply inputs to a specific cropland area based on soil type, fertility levels, and other endowments of the site, which in and by itself is helpful to the environment by preventing over-application of fertilizer (Batte). Under variable rate application, fertilizer inputs are increased in areas of high productivity and are decreased in areas of low productivity (Smith). The economic benefits of using variable-rate systems in agricultural production result from allowing fertilizer dollars to be spent on areas within a field where they will provide a response, and to be saved where response is unlikely (Varsa *et al.*).

The objectives of the study are twofold: First, it will examine factors that are likely to impact the decision of cash grain farmers to apply fertilizers and/or lime using a variable rate application technology (VRT). Second, it will explore the economic value of VRT by examining its impact on the per-acre costs of fertilizer and/or lime application.

Spatial variability due to soil type, type of crops grown, weather conditions, the method used in applying fertilizers, among others, all are factors capable of introducing variability in the per-acre

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cost of fertilizers. To this extent, a subsidiary objective of the study is determine how much

variation in the per-acre costs of these inputs among cash grain producers is explained by some

of these factors, with special emphasis being given to the role of VRT adoption.

Previous Research

Research examining the factors that influence the adoption of precision agriculture and the

economics of such adoption is on the rise. Daberkow and McBride (1998) used logit analysis and

data from a 1996 USDA survey to examine the determinants of precision agriculture adoption in

corn production. Findings indicated that operators who were less than 50 years of age, who used

computerized farm record systems, and who relied on crop consultants were more likely to adopt

precision agriculture. Higher adoption probabilities were also found to be associated with farm

size, farm profitability, expected yields, and farm location. Khanna used data from a 1997 mail

survey conducted on cash grain farmers in selected Midwestern states to analyze, among others,

the factors that influence the adoption of inter-related technologies (soil testing and VRT) for

site-specific crop management. In terms of findings pertinent to VRT adoption, the results

indicated higher adoption probabilities to be associated with farms located on relatively higher

quality soils, larger farms, and operators with higher levels of human capital. Based on the same

data as described in the previous study, Khanna *et al*. examined the current level and likely trends

in adoption of a variety of technologies for site-specific crop management. Survey results

indicated that low rates of adoption by respondents were associated with the uncertainty in

returns due to adoption, high costs of adoption, and lack of demonstrated effects of the advanced

site-specific technologies on yield and input-use.

The economic potentials of variable rate technologies were assessed in a number of studies. For example, Mahajanashetti *et al.* (1999) used a theoretical model to identify the ranges of spatial variability within multiple-land-class fields for economically viable VRT and the spatial variability required for maximum return to VRT. The study's findings illustrated that lower nitrogen and/or corn prices decreased the optimal return to VRT and reduced the range of spatial variability providing positive net returns to VRT. Accordingly, the study's findings allude to the possibility of lower VRT adoption rates when crop and input prices are low. A study by Batte found that the farm level economic performance of site-specific management depends on the attributes of the farm's soils and other resources, on farm's size, on the inherent variability in production for these resources, and on the previous management decisions. Other studies that assessed the economics of precision farming in general are those by Wolf and Buttel, Weiss, Lowenberg-DeBoer, Schnitkey *et al.*, English *et al.*, Peng and Bosch, and Popp and Griffin.

Multivariate Analyses

The farm operators in the sample were classified into two groups: those that reported applying fertilizer and/or lime with variable rate technology (7%), and those that reported otherwise and presumably have used uniform rate technology instead (93%). This classification allows for the construction of the binary dependent variable *y* (replaced later in the text by *ADOPT_VRT)* that is used in attending to the first objective of the study, the modeling of VRT adoption decisions. To the extent that *Y* is a discrete variable, estimation of the determinants of VRT adoption using ordinary least squares will result in biased regression parameters. To circumvent this outcome,

probit regression is used as in:

(1) $Y_i^* = \beta' X_i + \varepsilon_i, \qquad \varepsilon_i \sim N(0,1)$
        $Y_i = 1 \quad$ if $Y_i^* \succ 0$ (*operator adopts VRT*),
        $ = 0 \quad$ if $Y_i^* \leq 0$ (*otherwise*),

where X is a matrix of explanatory variables, and β is a vector of parameters to be estimated.

Unlike the random vairable Y_i ($i = 1, \dots, n$) which is observable, the variable Y_i^* is unobservable

since it is derived from a farm operator's utility function (see Huffman; Khanna). The expected

value of Y_i can be expressed in terms of the probability (P) of adopting VRT as in:

(2) $E[Y|X] = P(Y_i = 1)$
        $ = P(Y_i^* \succ 0) = P(-\varepsilon_i \prec \beta' X_i),$

Because the probit model in (1) is associated with the standard cumulative distribution

function $\Phi(.)$, its parameter estimates are obtained by a maximum likelihood technique (MLT).

MLT allows for the estimation of the probability ($\hat{P}_i$) that the ith farmer selects VRT over the

uniform fertilizer application method as in the following:[3]

(3) $\hat{P}_i = \Phi(\hat{z}_i) = \int_{-\infty}^{\hat{z}} \phi(u_i) \, du_i$
        $\phantom{\hat{P}_i} = \int_{-\infty}^{\hat{z}} (2\pi)^{-1/2} \exp(-u_i^2/2) \, du_i,$

where $\phi(.)$ is the probability density function of the standard normal, u_i (equivalent to $-\varepsilon_i$ in (2),

which is redefined to keep the algebra simple) is a random variable with mean zero and unit

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[3] The objective of MLT here is to find the estimator $\hat{\beta}$ that maximizes the likelihood of observing the pattern of

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variance, and $\bar{z} = \hat{\beta}' X$.

The probability density function (ϕ) and the estimated parameters $\hat{\beta}$ from (1) are then used to estimate the marginal effects (Greene) as in:

(4) $$\frac{E[Y|X]}{\partial X} = \phi(\hat{\beta}' X)\hat{\beta}.$$

The second objective is to examine the impact of adopting VRT on the per-acre costs of fertilizer and/or lime application (*FEXP*). This is accomplished by using a least squares regression model. Here, *FEXP* is regressed first against a set of explanatory variables including *y,* a dummy variable indicating use of VRT (i.e., $Y_i = 1$ if adoption occurs; 0 otherwise); then by testing the coefficient of *Y* for statistical significance:

(5) $$E_i = \alpha_0 + \sum \alpha_j x_{ij} + \alpha_{j+1} Y_{j+1} + \varepsilon_i,$$

Where *x* is an element of a vector of explanatory variables denoting farm and farm operator characteristics. Estimation of (5) is problematic due to two potential econometric concerns. First is the possibility that the decision to adopt VRT is determined jointly with per-acre costs of fertilizers, which if left uncorrected, would lead to simultaneous equation bias. Specifically, adoption of VRT has the potential of impacting yields and/or fertilizer expense. In the same vein, technology choice is impacted by cost of inputs as potential gains in revenues due to efficient use of fertilizers might entice operators to adopt VRT. A remedy to this potential bias,

VRT adoption observed in the sample.

which will produce consistent estimators, is to use an instrumental variable technique where the instrument, by construct, should be highly correlated with the regressors but uncorrelated with the error terms (see Greene; p. 288). The study mitigates the potential of simultaneous equation bias by substituting in (5) the predicted probabilities ($\hat{P}_i$) of adopting VRT (see equation (3)) for the dummy variable *Y*.

A second econometric concern in estimating (5) is the likely occurrence of a selection bias due to "self-selection". For example, farm operators may select VRT because they are more aware of its advantageous attributes (i.e., positive impact on the environment while potentially reducing costs), and are better able to afford the costly investment needed when adopting VRT. Accordingly, and because of this self-selection, farm operators are not assigned randomly to the two groups: VRT adopters and non-adopters. A consequence of this is that the two groups are systematically different. These differences may manifest themselves in the per-acre expenditures on fertilizers and could be confounded with differences due to VRT adoption (see Fernandez-Cornejo). If this self-selectivity problem is left uncorrected, results from estimating per-acre costs of fertilizers or lime using regression procedures could be biased. Heckman (1979) proposed a two-stage estimation method to test and to correct for self-selectivity in linear regression models. In the context of this study, the first stage involves the estimation of a VRT adoption model using the probit analysis as was done earlier (see equation (1)). Estimated parameters from the probit model are then used to estimate a random variable ($\hat{\lambda}_i$), also known as the inverse Mills ratio (IMR), as in the following:

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(6)
$$\hat{\lambda}_i = \frac{\phi(\hat{z}_i)}{\Phi(\hat{z}_i)} \qquad \text{if } Y_i = 1,$$

$$\hat{\lambda}_i = -\frac{\phi(\hat{z}_i)}{(1 - \Phi(\hat{z}_i))}) \qquad \text{if } Y_i = 0.$$

In the second stage of Heckman's technique, $\hat{\lambda}_i$ is then used as an additional regressor in the

linear regression model in (5). The significance of $\hat{\lambda}_i$ can be interpreted as a test for selectivity

bias, and its inclusion, therefore, allows for the consistent estimation of model's parameters.

The final specification for the fertilizer expenditure model after attending to the simultaneity and

self-selectivity concerns hence takes the following form:

(7)
$$FEXP_i = \alpha_0 + \sum \alpha_j x_{ij} + \alpha_{j+1} \hat{P}_{j+1} + \alpha_{j+2} \hat{\lambda}_{j+2} + \varepsilon_i$$
$$= \alpha' X + \varepsilon_i,$$

where X is an augmented matrix of k exogenous variables.

Yet another objective is to determine how much variation in fertilizer costs is explained by VRT

adoption. To accomplish this, (7) is first estimated using weighted least squares, and then, the

variation in *FEXP* is apportioned to the contribution of different explanatory variables with

special emphasis being given to $\hat{P}_i$ (i.e., the instrument that predicts VRT adoption) as in the two

cases discussed next.[4]

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[4] Development of this section in its entirety follows closely a similar discussion on variance decomposition by El-Osta and Johnson (pp. 6-7).

Variance effects

In the absence of any covariation effects, the unexplained variability in *FEXP* is decomposed into a variability component explained by the linear relationship between the dependent variable *FEXP* and each of the explanatory variables, and an unexplained variability component due to the error term as in the following:

(8) $\quad \sigma_{FEXP} = \sigma(FEXP \mid \alpha_0, \alpha_1, ..., \alpha_k) = \alpha_1^2 \, \sigma_{11} + \alpha_2^2 \sigma_{22} + ... + \alpha_k^2 \sigma_{kk} + \sigma_{\varepsilon},$

Where σ_{FEXP} is the unexplained variance of per-acre costs of fertilizer and lime (*FEXP*), α is an estimated parameter, σ_{gg} (where $g = 1, ..., k$) is variance of variable *Xg*, and σ_{ε} is the variance of error term ε.

The individual effect (V_J) in percentage terms that each of the explanatory variables has on the variation in *E* can be measured as:

$$V_1 = [\alpha_1^2 \, \sigma_{11} \, / \sum_{j=1}^{k} \alpha_j^2 \sigma_{jj}] * 100$$

(9) $\qquad V_2 = [\alpha_2^2 \, \sigma_{22} \, / \sum_{j=1}^{k} \alpha_j^2 \sigma_{jj}] * 100,$

$$..$$

$$V_k = [\alpha_k^2 \, \sigma_{kk} \, / \sum_{j=1}^{k} \alpha_j^2 \sigma_{jj}] * 100.$$

Variance-covariance effects

Equation (9) shows the extent that each variable alone contributes to the variation in per-acre costs of fertilizers and/or lime relative to all other variables. Yet a more useful variance decomposition allows for the incorporation of the variance effects along with those of the covariances as in the following:

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\begin{aligned}
\sigma_{FEXP} &= \sigma\left(FEXP \middle| \alpha_0, \alpha_1, ..., \alpha_k\right) \\
(10) \qquad &= \alpha_1^2 \sigma_{11} \quad + \alpha_1 \alpha_2 \sigma_{12} \quad + ... + \alpha_1 \alpha_k \sigma_{1k} + \\
&\quad\; \alpha_2 \alpha_1 \sigma_{21} + \alpha_2^2 \sigma_{22} \quad + ... + \alpha_2 \alpha_k \sigma_{2k} + \\
&\quad\; .... \\
&\quad\; \alpha_k \alpha_1 \sigma_{k1} + \alpha_2 \alpha_k \sigma_{2k} + ... + \alpha_k^2 \sigma_{kk} \quad + \sigma_\varepsilon,
\end{aligned}
$$

where Φ_E is the weighted variance of fertilizer cost, and Φ_{gg} and Φ_{gh} ($g \; h$) are the weighted variance of component X_g ($g = 1,.., k$) and the weighted covariance of components X_g and X_h, respectively. The variability of E as described in equation 8 can, hence be approximated by the sum of explained variance-covariance effects attributed to the model's explanatory variables (Ω) and unexplained variance due to an error term. Thus equation 10 can be rewritten as:

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(11) \qquad\qquad\qquad \sigma_{FEXP} = \Omega + \sigma_\varepsilon.
$$

Consequently, the variance-covariance effects, which are commonly referred to in the literature as coefficients of separate determination are computed as (see Burt *et al.*; Langemeier *et al.*; El-Osta and Johnson):

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$$VC_1 = (\alpha_1^2 \sigma_{11} + \alpha_1 \alpha_2 \sigma_{12} + ... + \alpha_1 \alpha_k \sigma_{1k})/\sigma_{FEXP}$$

$$(12) \quad VC_2 = (\alpha_2 \alpha_1 \sigma_{21} + \alpha_2^2 \sigma_{22} + ... + \alpha_2 \alpha_k \sigma_{2k})/\sigma_{FEXP}$$

$$.......$$

$$VC_k = (\alpha_k \alpha_1 \sigma_{k1} + \alpha_2 \alpha_k \sigma_{2k} + ... + \alpha_k^2 \sigma_{kk})/\sigma_{FEXP}.$$

The explained variation of the dependent variable *FEXP* is described by the goodness of fit

measure, R^2, which is equivalent to the following:

$$(13) \qquad R^2 = \sum_{j=1}^{k} VC_j = \Omega/\sigma_{FEXP},$$

where VC_j indicates the jth variance-covariance effect. The unexplained variation in *FEXP* is,

hence, equal to 1 minus R^2.

Data and Procedures

The study uses data from the 1998 Agricultural Resource Management Study (ARMS) to

examine first, the determinants of VRT adoption, then to assess the role that this technology

plays on the per-acre costs of fertilizer and/or lime application and on the variability of these

costs. The ARMS is conducted annually by the Economic Research Service (ERS) and the

National Agricultural Statistical Service (NASS).

Data collected by ARMS provide information on agricultural resource use and costs, and farm

production practices including use of variable rate application technology, among others. The

ARMS also collects data on farm sector financial conditions (e.g., income, assets, and debt), on

farm operator and farm household characteristics (e.g., operator age, education, race, gender, off-

farm work, *etc*), and on management and marketing strategies used on the operation. (USDA, 1996, p. 101).

The population of farms targeted in this study were those farms specializing in the production of any of the four major cash grain crops: wheat, corn, soybean, or grain sorghum.[5] The size of the sample used after excluding those where no expenditures were reported for fertilizers/or lime, and after excluding a few outlying observations was 1,233 (see figure 1). This sample, which represented a population of 255,077 farms from 37 states, accounted for 97% of the total farm sales reported in 1998 by farms producing primarily wheat, corn, soybean, or grain sorghum. Because ARMS utilizes a complex survey design, the task of producing unbiased and design-consistent estimates of variance requires the application of a replication method that employs a delete-a-group jackknife approach to variance estimation (Kott; Dubman).[6] A major benefit of utilizing this replication approach with the ARMS is that survey weight adjustments, such as for post-stratification and nonresponse, can be reflected in the variance estimates (Daberkow and McBride).

Table 1 shows the definition and the means of variables used in the modeling of VRT adoption decisions and of per-acre cost of fertilizer and/or lime. While most variables used in the two models are self-explanatory, the variables *RISKPERCP* and *MEANPI* need further elaboration. *RISKPERCP*, which by construct is designed to quantify farm operators' risk attitudes, is an

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[5] By definition, a farm is typed as a wheat farm, for example, if more than 50% of the farm's gross income originates from the sale of the wheat crop.

[6] The ARMS is a multifarme stratified survey with each observation representing a number of similar farms, the particular number being the survey expansion factor. Each expansion factor, which is the inverse of the probability

index constructed from ARMS based on farmers' answers to a set of ten questions pertaining to how they would react toward risk, including the use of risk management tools.[7] Underlying the design of this index is the notion by Bard and Barry (1998) that risk attitudes are reflected by operators' attitudes toward tools used in managing risk. The productivity index *MEANPI*, which is developed using data from the Natural Resources Inventory (NRI), is constructed for the purpose of providing information on the ability of the soil to produce crops (see Pierce *et al.* for details).

From table 1, more than 60 percent of the cash grain farms (specializing in wheat, corn, soybean, or grain sorghum) in 1998 were located in the Heartland region (see figure 2). On average, these operators were 51-years-old, were less likely to have a college education and to work off-farm, and were moderate in their attitudes toward risk-taking. The farm operators in the sample, on average, rented more acreage than they owned. The average size of farm for the sample was much higher than national average of 435 acres (USDA, 2001).

Figure 3 demonstrates the extent of variability in the per-acre cost of fertilizers by highlighting the interquartile range – a robust estimator denoting the difference between the upper and lower quartiles -- of the distribution of fertilizer costs. The figure reveals a sizeable variability in fertilizer expense as the middle 50% of the operations seems to have a $24 per-acre difference in

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of the particular farm being selected, is used to expand the ARMS sample to represent the population of all farms.
[7] The information solicited by the ten questions dealt with the following subjects: having adequate cash on hand to pay bills; using custom work; having to spread sales of commodities over the year, relying heavily on market information to make decisions; farming with new machinery; accepting the notion that concentration of farming operations in a single geographic area "substantially increases" overall risk; having adequate back-up management/labor to carry on production in case of emergency; carrying adequate hail/fire insurance, and hedging

the amount they expend on fertilizers. It is important to note, however, that the mix of farms used in the analysis—wheat, corn, soybean, or grain sorghum— is presumed to contribute a sizable portion of the variability in the per-acre costs of fertilizers.

Results and Discussion

The maximum likelihood estimates of the probit model are presented in table 2. Results indicate that 93 percent of the observation were correctly predicted in terms of their VRT adoption-decisions. The McFadden R^2, which is defined as 1 minus the ratio of the unrestricted to restricted log-likelihood function was 0.149. Both of the goodness-of-fit measures indicate that the probit model was performed quite reasonably, considering the cross-sectional nature of the data.

The results show that some of the demographic characteristics of farmers along with some farm-specific variables do play a major part in impacting VRT adoption- decisions. Specifically, the positive coefficient on the education variable indicates that those operators with higher levels of education are more likely to adopt VRT. The positive and significant coefficient on the education variable is consistent with expectation, as the nature of VRT technology requires the ability to comprehend and decipher information, and is similar to findings by Khanna. The marginal effect of the education variable indicates that the probability of adopting VRT increase by 0.0091 for every additional year of education. The positive sign on *SIZE* (measured in tillable acres) variable indicates that the likelihood of adopting VRT increases with size of operation. The

by using futures/options.

positive association found between size of farm and the decision to adopt VRT is consistent with the finding by Daberkow and McBride (1998). In contrast, the negative sign on the variable used to proxy farmers risk attitudes indicates that farmers who are predisposed toward taking risks are less likely to adopt VRT. In terms of regional location of the farm, cash grain farmers located in the Northern Crescent (as delineated by the USDA production regions, figure 2), in the Northern Great Plains, in the Prairie Gateway are all less likely to adopt VRT than those farmers located in the Heartland. A likely explanation for the higher likelihood of VRT adoption in the Heartland is its higher share of acreage under corn, with its attending higher usage of fertilizers and/or lime.

Table 3 shows the results from estimating the per-acre costs of fertilizer and/or lime application. The resulting R^2 value of 0.235, while fairly low, is considered reasonable given the cross-sectional nature of the data. Results show the importance of many factors (with varying directional influence) including specialization in corn production expected precipitation, and the farm's regional location. Results also show no economic benefit from adopting VRT since the finding of a 9 dollars reduction in the per-acre costs of fertilizer application was not statistically significant.

The low value of R^2 in table 3 implies that much of the variation in per-acre cost of fertilizer can not be explained by the variables used in the model. In terms of explaining variability in cost of fertilizer, the impact of VRT is found to be minimal. In terms of variance effect, less than 1% of the explained variance in fertilizer cost is attributed to VRT adoption. When considering both the variance- and the variance-covariance effects, what emerged as a primary contributor to

variability in the per-acre cost of fertilizer was the level of specialization in corn production, a result that fits with expectations.

Concluding Remarks

The study has examined the determinants of VRT adoption using data from the 1998 ARMS survey. In addition, the study examined the role of such adoption on the per-acre costs of fertilizers and/or lime and of the contribution of such adoption on the variability of fertilizer costs. Findings revealed the importance of size, among others, in increasing the likelihood of VRT adoption. Once adopted, the study has found that farmers specializing in the production of primary cash grains (e.g., wheat, corn, soybean, or grain sorghum) would not significantly alter their per-acre cost of fertilizers. Findings also revealed the importance of level of specialization in corn production in explaining the variability in the cost of fertilizers.

When environmental regulations are imposed on production activities, they for the most part tend to impact larger-sized farms. It has been noted that as more regulations are imposed, not all farms will be able to comply, and in fact, the regulations, particularly if they are costly to implement, may even force some farms to exist from farming (Atwood and Hallam, 1993). To the extent that the study has demonstrated no significant reduction in the cost of fertilizer by VRT, farmers, particularly those operating small farms, will not have the incentive to adopt VRT, particularly because of its high-cost. Accordingly, and because of the capability of VRT to benefit the environment, the idea of cost sharing or subsidies by the government to small farmers in particular who are interested in adopting VRT but who could not afford its cost might be a

viable policy option. It needs to be noted, however, that if VRT is to produce any environmental benefit with its attending justification for some type of cost-sharing by the government, environmental considerations need to be incorporated explicitly into the monitoring and farm production decisions.

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Table 1. Definition and Means of Variables Used in the Analysis

Variable	Definition	Means[1]
EDYEARS	Education of farm operator (years)	13.24
OPAGE	Age of farm operator (years)	51
OCCUPF	Occupation of farm operator (=1 farming; 0 otherwise)	0.62
RISKPERCP	Operator's risk perception (index:10=least risk taking, 50=most risk taking)	29.09
SIZE	Farm size, measured as total tillable acres (100 acres)	5.21
SIZESQ	Farm size, squared	91.63
TENURE	Rented acres / total operated acres	0.62
CREDITRS	Credit reserves ($1,000)	20.99
SPECIALIZ	Value of corn sales / total value of sales	0.37
MEANPI	Soil productivity (index: 0=least productive, 100=most productive)	81.82
RAIN	County's average monthly rainfall, millimeters (1960-1992)	862
HEARTLAND	Farm location (=1 Heartland; 0 otherwise)	0.61
NRTHCRST	Farm location (=1 Northern crescent; 0 otherwise)	0.12
NRTHPLAN	Farm location (=1 Northern Great Plains; 0 other wise)	0.07
PRGATEWY	Farm location (=1 Prairie Gateway; 0 other wise)	0.12
MISSPORT	Farm location (=1 Mississippi Portal; 0 other wise)	0.03
OTHERREGN	Farm location (=1 Other Crop Producing Region; 0 otherwise)	0.05
ADOPT_VRT	Fertilizer variable rate technology (=1 adoption; 0 otherwise)	0.07
FEXP	Fertilizer expense (including custom application costs) per tillable acre ($/acre)	27.93

[1] Coefficients of variation [(Standard Error/Estimate)*100] of all estimates are 25% or less.

Table 2. Regression Estimates for the Probability of VRT Adoption, 1998

Variable	Estimated Coefficient[a]	t-ratio	Marginal Effects
INTERCEPT	-1.3651	-1.67*	-0.1616
EDYEARS	0.0773	1.96**	0.0091
OPAGE	-0.0001	-0.01	-0.0000
OCCUPF	0.1158	0.70	0.0137
RISKPERCP	-0.0456	-2.10**	-0.0054
SIZE	0.0377	1.69*	0.0045
SIZESQ	-0.0004	-0.92	-0.0001
TENURE	-0.0834	-0.53	-0.0099
CREDITRS	0.0005	1.04	0.0001
SPECIALIZ	0.2411	0.68	0.0285
NRTHCRST	-0.6384	-2.45**	-0.0756
NRTHPLAN	-0.9819	-2.07**	-0.1162
PRGATEWY	-0.7469	-2.78***	-0.0884
MISSPORT	-1.3866	-0.29	-0.1641
OTHERREGN	-0.4277	-1.42	-0.0506

[a] Indicates statistical significance at the 0.10 (*), 0.05 (**), and 0.01 (***) levels.
Sample size = 1,233.
Log likelihood = - 56034.
Log likelihood, restricted = -65871.
McFadden's R^2 = 0.149.
Percentage correctly Predicted = 92.77.

Table 3. Regression Estimates for the Per-Acre Cost of Fertilizer, 1998

Variable	Estimated Coefficient	t-ratio	Variability Decomposition	
			Variance Effect (%)	Variance-Covariance Effect
INTERCEPT	16.068	1.20	0.00	0.000000
OPAGE	-0.104	-0.91	3.10	0.007187
OCCUPF	0.968	0.40	0.32	-0.001053
SIZE	0.109	0.75	1.04	-0.006392
SIZESQ	-0.001	-0.83	0.54	0.002994
TENURE	0.843	0.65	0.53	-0.000570
SPECIALIZ	19.343	2.97***	52.87	0.125265
MEANPI	-0.044	-0.49	0.24	-0.001685
RAIN	0.017	2.68***	20.32	0.054188
NRTHCRST	-3.955	-1.03	2.22	-0.000297
NRTHPLAN	-9.727	-2.64***	8.08	0.032422
PRGATEWY	-6.014	-1.71*	5.37	0.023400
MISSPORT	-9.778	-1.46	3.22	0.002693
OTHERREGN	2.866	0.83	0.59	0.000777
$\hat{P}$	-8.921	-0.86	0.67	-0.005548
λ	1.648	1.24	0.87	0.001926
R^2	0.235			
F-Statistic	113.8*			

[a] Indicates statistical significance at the 0.10 (*), 0.05 (**), and 0.01 (***) levels.
Sample size = 1,233.

Fertilizer/or Lime Applied:
Variable Rate Technology (6.6%)

No Fertilizer/or Lime Applied:
(8.0%)

Fertilizer/or Lime Applied:
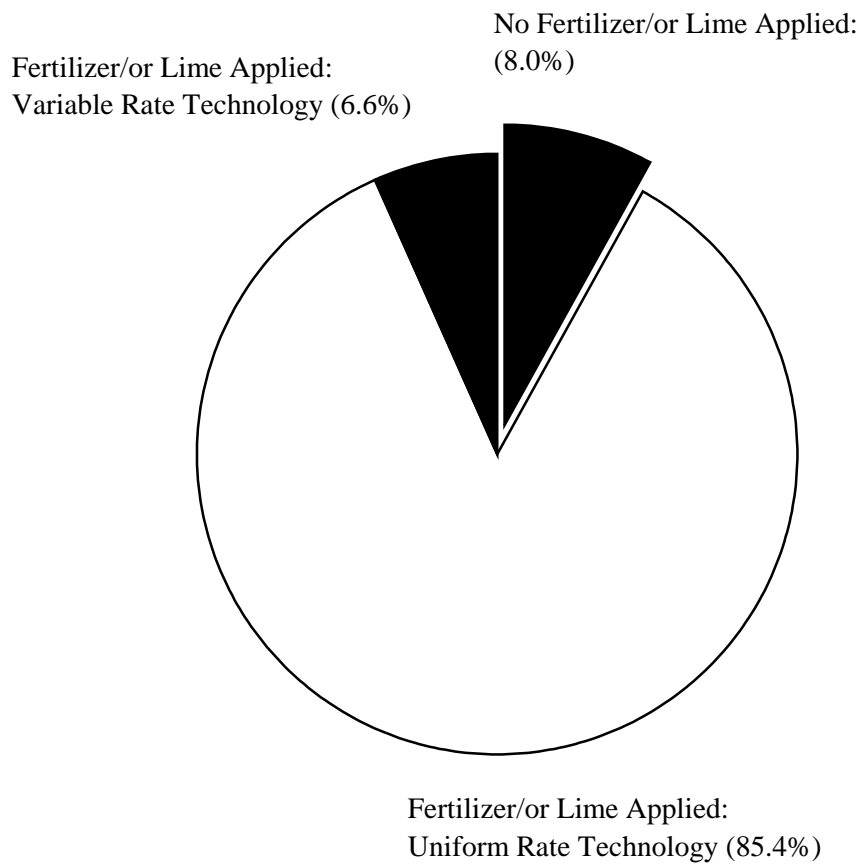Uniform Rate Technology (85.4%)

Figure 1. Distribution of Cash Grain (Wheat, Corn, Soybean, Grain Sorghum) Farms by Type of Fertilizer/or Lime Application Technology, 1998

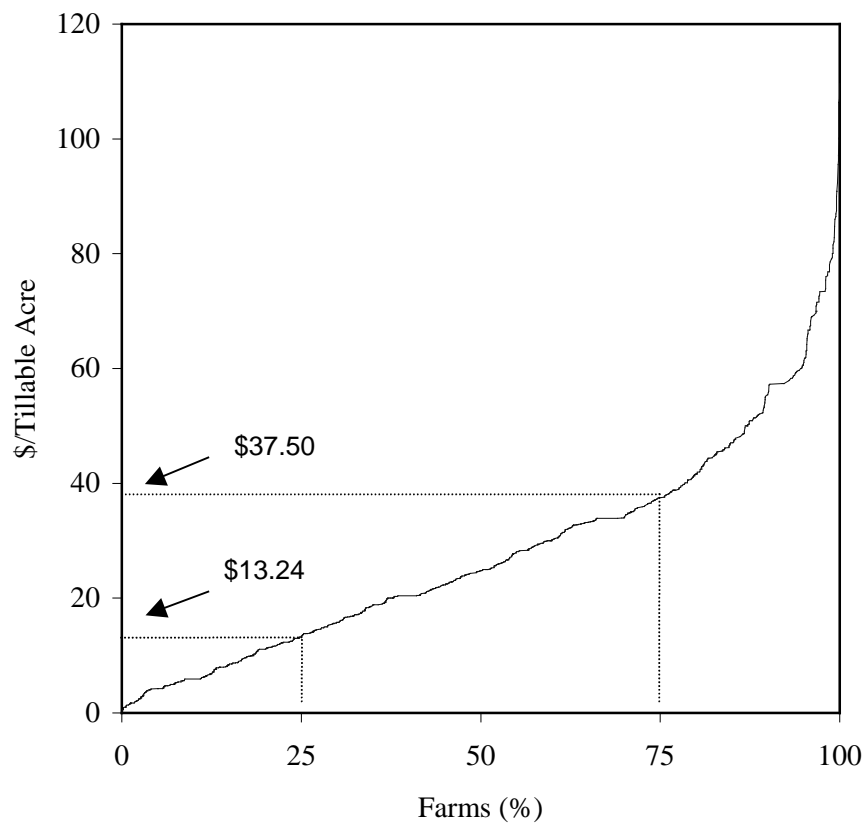**Figure 2. Economic Research Service Farm Resource Regions.**

Figure 3. Cumulative Distribution of Per-Acre Cost of All Fertilizer and Lime in Cash Grain Production (Wheat, Corn, Soybean, Grain Sorghum), 1998