MARGINAL IMPACT OF EDUCATION, FINANCIAL PERFORMANCE, AND GOVERNMENT PROGRAMS ON THE ADOPTION OF PRECISION AGRICULTURE TECHNOLOGY

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ABSTRACT

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Precision agriculture assists producers in practicing good stewardship on their agricultural lands. The Conservation Security Program (CSP) and the Environmental Quality Incentive Program (EQIP) have been developed by the government to facilitate the adoption of precision agriculture and other conservation programs.

This study uses survey data and a multinomial logit model to analyze the marginal impacts of government programs, farm financial performance, and visits by precision agriculture sales personnel on the choice of fertilizer application method. Visits by precision agriculture sales personnel, from private industry, were also modeled as a combined effect variable with government programs to represent changes in the traditional flow of government assistance.

Overall, government programs significantly and positively impacted the adoption of variable-rate fertilizer technology within the group of non-adopters of variable-rate technology. However, within the group who have adopted variable-rate fertilizer application using management zone technology, government programs negatively and significantly impacted the adoption of additional precision agriculture technology.

Programs should be designed to address the attributes of government programs, training, and financial needs.
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CHAPTER 1. INTRODUCTION

Agriculture has experienced a large number of mechanical and biological inventions during the last century. After the west was settled, the farmer’s land base became limited and farmers began to explore new ways to increase crop production with a limited supply of land. Much research has been conducted on the farmer’s adoption of new technology (Gardner and Rausser, 2001). There are numerous independent variables that will impact the farmer’s decision on whether to adopt a new technology. Some of those variables are farm size, the farmer’s risk attitude, crop rotation, geographical location, government programs, education, and unbiased public research.

Government programs are one of the independent variables Gardner found to impact the adoption of new technologies. If a new technology is subsidized by a government program, the elements of learning-by-doing and experience may improve the profitability of those technologies that have environmental benefits, and the farmers can recognize their economic advantage (Gardner and Rausser, 2001). Once economic advantage is presented, adoption may persist in the long run even if government funding is stopped. If the economic advantage is not shown and the government funding is stopped, the adoption of the new technology will be short-lived.

The farmer will make varying decisions on the adoption of new technology depending on how much public unbiased research has been conducted on the new technology. Education is the most important form of human capital (Gardner and Rausser, 2001). Since all new technologies might not be directly profitable for every farmer due to intangible environmental benefits, the farmer’s education level may help him/her make better decisions which will increase farm profitability. Rahm and Huffman developed the
efficiency of adoption as the absolute difference between actual and predicted adoption behavior (Gardner and Rausser, 2001). In the case of reduced tillage adoption, the efficiency of adoption increased when farmers gained information by private sector media sources or attended a short course at Iowa State University. However, the farmer’s active years of farming or participating in meetings, field days, or demonstrations held by the Extension Service did not have a significant effect.

This research is focused on the adoption of variable-rate fertilizer application which is a new precision agriculture technology. Precision agriculture involves a range of management practices that attempt to utilize site-specific information at the field level, such as soil characteristics and weather conditions, in order to adjust farm inputs and ultimately achieve optimal output (National Research Council, 1997). Precision agriculture has been practiced since the early 1990s, and the adoption rate of the new technology has been slower than experts had predicted. This has been due to unexpected costs such as incompatibility between software, monitors, and equipment; repair delays; and expensive equipment costs. Lowenberg-DeBoer (1997) contends that precision agriculture will not fit the classic S curve model of technology. The classic S curve model provides a good pattern for the growth of demand for a new product. The pattern is split into three major segments: introduction and early adoption, acceptance and growth of the market, and maturity with market saturation. Precision agriculture is immature and lends itself to tinkering, public and private institutions are not yet prepared, and especially due to the changes in farm policy, risk is increasing in agriculture (Lowenberg-DeBoer, 1997).

The research of science and economic benefits of precision agriculture is more short-lived than undisputable long-term research. The private industry (short-term
research) has been leading the education frontier to the farmer. Private research and
development appear to generate their returns in the immediate term (after about 8-15
years), while public research and development investments seem to pay off in the longer
run (after 15-25 years) (Gardner and Rausser, 2001). The large potential
commercialization of precision agriculture technologies by numerous private enterprises
large and small has fueled education on the use and possible benefits of these new
technologies.

In contrast, universities have received little federal funding for precision agriculture
research. At the same time, most land-grant universities have down-sized personnel,
leaving the remaining researchers and Extension educators with the task of maintaining
important basic research, while being asked to evaluate not only a continually changing
array of precision agriculture equipment but to evaluate the economic and environmental
benefits of this technology with little industry or government support.

In year 2000, USDA issued its first call for grant proposals on precision agriculture.
Of over 30 proposals submitted, only 6 were granted. In 2001, the same program again
called for proposals, and fewer than 10 were funded. In 2002, the program was
discontinued (Franzen, 2003). Most precision agriculture research is funded in the United
States by redirection of United States Department of Agriculture Research (USDA-ARS)
programs, state fertilizer check-off research, commodity group funding, and EPA 319
water quality grants.

Consequently, most industry education ends up being “sales-oriented”
demonstrations, with companies referring to hastily conducted and scientifically under-
researched “on-farm” trials.
A current snapshot of the current precision agriculture industry is that there has been much investment in private research and limited investment in fundamental and public research. Precision agriculture has become a technology that many are implementing into policy marking and their own production practices to help control sensitive environmental issues.

In the past five years, public attention has been turned toward nutrients in the Mississippi River Basin and especially the growing hypoxia problem in the Gulf of Mexico, which may be related to nitrate loading. The Clean Water Act written by the Environmental Protection Agency has many purposes, and one is to regulate nonpoint pollution within the United States’ watersheds. Agricultural practices are considered the largest contributor of surface water quality degradation in terms of sediment, runoff of nutrients, and leaching of chemicals (Crutchfield et al., 1993). Nitrates and phosphorus sediments are suspected to be the primary source of impairment to fresh water bodies, affecting one-third of the surveyed lake acres, streams, and rivers in the U.S. (USEPA, 1998). It has been estimated that only 30 percent to 70 percent of nitrogen fertilizer used in U.S. agriculture is actually recovered in crops (Legg and Meisinger, 1982).

The United States Department of Agriculture (USDA) and the Natural Resources Conservation Service (NRCS) has designated precision agriculture as a means to begin regulating the inefficient use of fertilizers, which may eventually minimize nonpoint pollution in the river watersheds. The National Wildlife Federation suggested that “farmers and ranchers who are undertaking or are willing to undertake land management practices that enhance the environment should be given financial and technical assistance necessary to carry out these activities” (2003, p. 2). Farmers will receive incentives for
demonstrating good land stewardship with the development of the new Farm Security and Rural Investment Act of 2002.

Farmers have traditionally signed up for the Farm Security and Rural Investment Acts (Farm Bill) programs at Farm Service Agency offices. These government service branch offices have been thought of as a one-stop shop for becoming eligible and enrolling in government programs. This “one-stop shop” process is changing due to the limited NRCS personnel and the forecasted wide acceptance of these new agri-environmental government programs. The NRCS is creating another avenue for the successful implementation and rollout of these programs. The private sector of precision agriculture is involved to help determine the farmer’s local resource concern and ways to manage these concerns. Certified private industry personnel act on behalf of the NRCS in creating best management plans that will enable the farmer to receive their government payments. Figure 1 shows the traditional (one-stop approach) and the current flow of information between the farmers and the government offices. This research will address how the newly created avenue and change in process impacts the adoption of precision agriculture technology by enrolling in government programs which promote adoption through the precision agriculture industry.

With the creation of the Farm Security and Rural Investment Act of 2002 and more emphasis on agri-environmental versus commodity programs, this research will study how these new agri-environmental government programs impact the adoption of precision agriculture technology. The government programs variable will be modeled by a discrete choice variable of whether the farmer is interested in enrolling in the new agri-environmental government programs or not. Financial leverage, a measure of financial
performance or debt burden, and net worth will be analyzed to assess potential cash
constraints and determine if financial constraints limit the diffusion of precision
agriculture. Finally, this research will study how training through industry sales personnel
impacts the adoption of precision agriculture. Education in this research will be
represented by sales visits the farmer receives from the private industry sales personnel.
This variable will be used since the private industry is contributing to a large amount of
education of precision agriculture. This research focuses on two policy variables,
education (sales and training) and government programs, and how they impact the
adoption of precision agriculture. These policy variables can either be re-evaluated or
promoted. Particular emphasis was also placed on financial performance with alternative
fertilizer application rates.

*      New information flow with 2002 Farm Bill agri-environmental programs.
*      Traditional information flow with previous government programs.

Figure 1. Flow of information in government programs.
Objectives and Hypothesis

Specific objectives are to (1) determine the level and incentives for alternative fertilizer application technologies; (2) develop a multinomial logit model to model the marginal impact of government programs, private industry sales and training, and financial constraints on the adoption of precision agriculture; and (3) suggest policy recommendations to facilitate the adoption of environmental agriculture technologies. This study will test the hypothesis that government programs and private industry sales and training enhance the adoption of precision agriculture and that financial constraints play a significant role as well.

Method

This study uses survey data and develops a multinomial logit model to analyze the marginal impacts of government programs, farm financial performance, and visits by precision agriculture sales personnel on the choice of fertilizer application method. The organization of this paper proceeds with a literature review focusing on prior studies and benefits of precision agriculture and variable-rate fertilizer technologies, discusses the new agri-environmental government programs, reviews the main steps toward successful government programs, and identifies variables that are used in the analysis. The methodology, data collection, and data management are discussed with a focus on answering the following research questions:

(1) What is the marginal impact of environmental-based government programs on the adoption of precision agriculture?
(2) What is the marginal impact of education on the adoption of precision agriculture?

(3) What is the marginal impact financial performance has on the adoption of precision agriculture?

(4) How is the deviation from the traditional “one-stop” adoption process to two-step processes (that include a significant role of private industry) affecting the adoption of environmentally friendly agricultural technology?

The answers to these questions are presented in the results section followed by suggestions and policy recommendations.
CHAPTER 2. REVIEW OF RELEVANT LITERATURE

Prior Studies and Benefits of Precision Agriculture

Precision agriculture has been practiced since the early 1990s, and the adoption rate of the new technology has been slower than experts had predicted. In 1997, Lowenberg-DeBoer contended that precision agriculture will not fit the classic S curve model of technology. As earlier defined, the classic S curve model usually consists of three segments: introduction and early adoption, acceptance and growth of the market, and maturity with market saturation. In 1998, Lowenberg-DeBoer created an alternative adoption scenario for the adoption of precision agriculture technology, titled the “Bumpy Road to Precision Agriculture.” This alternative scenario is presented in Figure 2. Lowenberg-DeBoer explained that bumpiness has been due to unexpected costs such as incompatibility between software, monitors, and equipment; repair delays; and expensive equipment costs. However, Lowenberg-DeBoer did not discuss deviations from traditional “one-stop shopping” that farmers are accustomed to for agri-environmental government programs.

Figure 2. Bumpy road to precision agriculture: an alternative scenario (Lowenberg-DeBoer, 1998).
Gardner (Gardner and Rauser, 2001) has done extensive research on the farmer’s adoption of new technology. There are numerous independent variables that he identified to impact the farmer’s decision on whether to adopt a new technology or not. Some important variables are mechanical equipment, farm size, and profitability. He researched the minimum farm size that can support new technologies. He noted that the risk attitude of the farmer should also be considered. The level of public unbiased research on a new technology will help the farmer decide on adoption of new technologies. Geographical considerations should be considered since the farther away from a regional center, the longer a farmer will take to make a decision on the adoption of a new technology. Crop rotation is an important factor when one is studying multi-product farms. Crop rotations generate well-known benefits since different crops might more efficiently utilize the fertility of the soil. For example, corn planted after soybeans will help minimize nitrogen costs since soybeans have the ability to fix nitrogen in the soil.

Variable-rate fertilizer technology was one of the first frontier technologies of precision agriculture. Variable-rate fertilizer application is defined as a technology which applies variable rates of fertilizer while the application machine is moving across the field. Refinements have been done over the years in creating the variable-rate prescription. Hennessy, Babcock, and Fiez (1996) found that average fertilization levels chosen under uncertain information on the exact crop needs are likely greater than the levels chosen with site-specific information.

Variable-rate fertilizer application may provide both environmental and economic benefits to the farmers and society as a whole. Economic studies show the farmer would
generally benefit from this technology by decreasing variable costs (Intarapapong, 2002). Environmentally, applying this technology on corn would result in the maximum benefit to the environment, reducing nitrogen runoff and phosphorus loss in sediment by 4.90 percent and 1.55 percent, respectively (Intarapapong, 2002).

Babcock and Pautsch (1998) found that moving from uniform to a variable-rate fertilizer, corn yield would increase by 0.05 to 0.50 bushels per acre and would reduce fertilizer costs by $1.19 to $6.83 per acre.

Financial limitations might prove to be barriers to the adoption of precision agriculture technology (Lowenberg-DeBoer, 1997). Dr. Lowenberg-DeBoer showed the decline and static adoption in phase two, “discouragement due to lack of support and low profitability” (Figure 2); these possible cost limitations can be calculated from the farmer’s net worth and farm assets. The financial leverage ratio is the ratio of total farm debt to farm equity, and it measures the firm’s total obligations to creditors (lenders) as a percent of the equity capital provided by the owners (Barry et al., 2000) and the degree of indebtedness or ability to meet other financial obligations. The Dupont Identity states that total assets must be equaled to the total liability plus equity. When both sides of the equation are divided by equity, we derive a proxy for the leverage ratio. Barry et al. (2000) states that the standard rule of thumb for maximum leverage ratio is one (50 percent debt, 50 percent equity) for farmers. Lenders prefer borrowers to have at least as much invested in their own business as lenders do. However, the size of farm, the percentage of leased land, and other variables will affect the lender’s decision in “acceptable” leverage ratio. Leverage is used in this study to assess the impact of financial limitation on the adoption of alternative fertilizer application rates.
2002 Farm Security and Rural Investment Act

With an 80 percent increase in funding to conservation programs in the 2002 Farm Bill, the question arises why there was a shift in funding from commodity to conservation programs. In the past, the Farm Bills of 1985 and 1990 included initiatives to reduce erosion and help the environment. In a study conducted by Wu et al. (1997) on the economic and environmental impacts of the Farm Bills of 1985 and 1990, the authors concluded that farmers were more responsive to government policy incentives and less responsive to market signals. More farmers will participate with relaxed policy, but this leads to higher government program costs (taxpayer costs) and does not promote farmer responsiveness to market price signals. Batie (1994) noticed the Farm Bill policies were switching from a farm income goal-based program to environmental quality concern programs. In Batie’s research, the author concluded that the more involved the farmer is in the problem definition and solution to the environmental problem, the more successful the program will be, highlighting the importance of extension.

The Farm Security and Rural Investment Act of 2002 (2002 Farm Bill) has an increase of 80 percent in the Title II funding for agri-environmental programs. The additional funding is intended to help producers promote conservation and improve the quality of soil, water, air, energy, and animal and plant life. One method to increase the cost-effectiveness of conservation programs is to shift funding to agri-environmental incentive payments designed to encourage cleaner, less-polluting production practices (Ribaudo et al., 1999).
There are two major environmental programs, the Conservation Security Program (CSP) and the Environmental Quality Incentives Program (EQIP). In 1996, EQIP was first introduced and designed to help improve water quality, conserve both ground and surface water, reduce soil erosion from cropland and forestland, and improve rangeland (NRCS A, 2002). The CSP provides a comprehensive, locally driven approach to agricultural conservation on lands in production and is flexible enough to include payments to “good actors” (Harkin, 2002). “Good actors” are defined as farmers who currently implement conservation practices into their farming operation.

The Congressional Budget Office has estimated that the Conservation Security Program will provide approximately $2 billion to farmers over the next ten years for conversation practices. “The Conservation Security Program will provide payments for producers who have historically practiced good stewardship on their agricultural lands and incentives for those who want to do more” (NRCS B 2002, p. 2). The conservation benefits gained will keep farms and ranches more sustainable and increase the benefits provided to all Americans through improved natural resources (NRCS B, 2002).

As a part of CSP, farmers and ranchers will be interviewed to determine resource concerns and establish the current level of conservation treatment the farmers are implementing on their eligible agricultural lands. A resource concern is defined as a natural resource with conditions that may be sensitive to change by natural forces and human activity. There are nine main areas which the management programs have to reduce, and they are grouped into four categories: surface water (sheet and rill erosion, nitrogen, phosphorus, and pesticides), ground water (nitrogen and pesticides), air (wind erosion and carbon emissions), and soil (decreasing productivity).
Eligible practices included land management and vegetative and structural practices that protect the resources, except animal waste management related structures (NRCS A, 2002). Once the level of current stewardship and the possibility of future conservation treatment plans are assessed, the farmer will enroll in one of three levels (tiers) of participation in the Conservation Security Program. Tier 1 conservation security plans would address at least one resource concern for a minimum part of the operation for five years. The annual payment will include an amount equal to 5 percent of the base payment (derived from the average rental rates for the 2001 crop year by land use), cost-share and maintenance payments (county average costs for the 2001 crop year), and enhancement payments not to exceed $20,000. Enhanced payments might be added at the discretion of the Secretary of Agriculture for such things as applying practices that exceed the minimum requirements for the tier, participating in research and demonstration projects, cooperating with other producers to implement watershed or regional resource conservation plans that cover at least 75 percent of the targeted area, or carrying out assessments and evaluations relating to practices included in a conversation security contract (NRCS B, 2002).

Tier II conversation security plans will address at least one resource concern for the total agricultural operation for five to ten years. This annual payment includes 10 percent of the base payment, with cost-share and maintenance payments, and enhancement payments not to exceed $35,000. Tier III conversation security plans would address all applicable resource concerns for the total agricultural operation for five to ten years. Annual payment includes an amount equal to 15 percent of the base payment, cost-share and maintenance payments, and enhancement payments not to exceed $45,000.
With the implementation of the new conservation programs, the NRCS currently does not have adequate staffing to carry out the development and monitoring of the conservation security plans. Therefore, the USDA has established Technical Service Providers. A Technical Service Provider (TSP) could be an individual or private and public agency. They must meet certification standards set forth by the NRCS and remain in good standing with the rules and regulations. The NRCS will only make payment to a producer for technical services obtained from a TSP who has been certified by the NRCS.

**Successful Precision Agriculture Programs**

The new environmental quality programs seem to have a higher probability of success when the farmer is engaged in creating the solution to the resource concern, but the cost of abatement becomes a factor. In a study on the Rural Water Quality Program in the Grand River Watershed of the Regional Municipality of Waterloo, Ontario, Weersink et al. (2001) concluded that three items will lead to a precision agriculture program’s success. The level of subsidization must be sufficient to cover the private abatement costs of the producer. The choice of which technologies to support should depend upon the level of damages that can be avoided. Finally, the objectives of the program (improvement of environmental quality) need to be clearly stated as guiding principles.

Research has suggested that variable-rate fertilizer precision agriculture technology may reduce the amount of fertilizer the farmer applies with little negative effects on yield when the fertilizer prescription is adequately and intellectually developed compared to the traditional uniform fertilizer application.
To minimize the nonpoint pollution problem, the government has moved the Farm Bill’s focus to agri-environmental programs. In order to be successful, the programs must be flexible with the farmer taking an integral part in the decision-making process with subsidized costs. With that in mind, this study was created to research how the new agri-environmental government programs will influence the adoption of variable-rate fertilizer precision agriculture technology giving deviations mentioned in Figure 1.

Financial Characteristics of Survey Study Area

The study survey area of this research was mainly in the state of North Dakota and surrounding counties in western Minnesota and northern South Dakota. North Dakota farmers use a wide range of crops in their farming practices since the soil and growing conditions can support a wide variety of crops. The financial characteristics of the North Dakota Farms for 2000-2002 (Swenson, 2002) provide demographic information for the survey area. A map of the survey area can be found in Appendix C. The research results show that farms in the survey area are getting larger with an average of 2,033 acres, and like the national trend, there was an increase in off-farm wages. The median gross revenue increased from the prior year by 37 percent. The median farm assets ($575,606) and liabilities ($284,828) increased by 40 percent and 60 percent, respectively, when compared to 2001. The farmer’s median age has increased from 39 years of age to 44 years of age, and the net farm income increased 37 percent over the reported 2001 numbers to $38,079. This study area is similar to farming communities all across the United States, with increasing farm sizes and ages of farmers (Swenson, 2002).
CHAPTER 3. METHODOLOGY AND DATA

Theoretical Model

Farmers adopt production methods that they perceive as the most profitable and convenient methods, given the conditions of their practice. It is assumed that choosing a particular method of fertilizer application technology reveals that a farmer perceives one system as being relatively more profitable than the other alternatives.

Profits of the \( j \)-th farmer from producing crops using the \( i \)-th production technology are \( \pi_{ij} \) (Nganje et al., 2002). These profits are a function of farm attributes, \( X \), including total acres, soil type, various crops that the farmer has in his/her rotation, land location, and the value of crop revenue. Profit is being used in this model since it captures all the items one could not represent in a model. Therefore, the expected utility of potential profits, \( U(\pi_{ij}(X)) \), is a function of farm attributes. For a grower to shift from one method of fertilizer application to another, the expected utility from potential profits under the \( i \)-th production method must be at least as large as those under the base method that the farmer is already implementing:

\[
\Delta U(\pi) = U(\pi_{ij}) - U(\pi_{0j}) > 0, \tag{1}
\]

where \( i = 0 \) denotes the base fertilizer application technology. In this research, the base method of fertilizer application is a uniform (flat rate) application.

One of the principal problems when dealing with calculations of the costs associated with precision agriculture technology is that the majority of the costs are social. Farmers may not realize or appreciate the ecological costs, and their perceptions of profits and costs may be unrealistic or untrue. As a result, farmers may not adopt new precision agriculture variable-rate fertilizer technology because they do not fully account for the...
social costs of their actions. Education is essential in making farmers aware of both the
ture costs of uniform fertilizer application and of the alternatives. In the present
framework, the goal is to assess whether or not improving farmer education through sales
training and government programs will make farmers more aware of the costs of uniform
fertilizer application and consequently help the adoption of better precision agricultural
technology practices.

To accomplish this, changes in government programs must increase the difference
in expected utility from perceived profits between uniform fertilizer application and the
alternative methods of production. Government programs and sales training must either
make farmers more aware of the full ecological costs of uniform-rate fertilizer application
and/or the profit potential in using fertilizer application technology methods other than the
uniform application. However, individual farmers respond to education and government
programs differently, and financial strength as well as social and personal characteristics
may limit an individual farmer’s adoption of new precision agriculture technology.
Consequently, this issue must be addressed through the development of an empirical
model.

The model adopted in this study follows Caviglia and Kahn (2001) and Adesina
and Chianu (2000) in assuming a random utility framework for the farmers’ utility
maximization problem. Given this, each farmer maximizes expected utility by opting for
the production practice with the highest perceived profits, given by

$$U(\pi_{ij}(x)) = f_{ij}(x) + \varepsilon_{ij},$$

(2)

Here $f_{ij}(x)$ is a deterministic function of farm attributes, and $\varepsilon_{ij}$ is a random variable
representing unobserved attributes. It is not necessary to estimate each farmer’s utility or
profit function. The probability of adopting a particular production method as a function of farm and farmer attributes can instead be estimated using a discrete choice model. This can be accomplished by assuming \( f_0(X) \) takes the form \( \beta_i X_j \), where \( \beta_i \) is a vector of parameters associated with the production method and \( X_j \) is a vector of observed farm and farmer attributes.

Translating the difference in expected utility into a workable limited discrete choice model requires assuming a distribution for the difference between \( \epsilon_{ij} \). Assuming the \( \epsilon_{ij} \) are random independent variables following a Weibull distribution, the distribution of the difference between the \( \epsilon_{ij} \) is logistic (Domencich and McFadden, 1975). Since farmers are assumed to choose between three alternative fertilizer application technologies, the model outlined in Equation 2 reduces to a multinomial logit were the probability of implementing a particular fertilizer technology is a function of both farm and farmer attributes, including measures of financial performance, enrollment in government programs, and visits by precision agriculture sales personnel.

Farmers can choose between many various forms of variable rate application. In this research, the focus is on grain and sugarbeet farmers within North Dakota, South Dakota, and Minnesota. This research will focus on the three main options in applying fertilizer. To apply fertilizer at a variable rate, a specialized controller must be able to control the rate of fertilizer that is to be applied spatially across the field. Also, there are numerous variations of each variable-rate technology within the industry, but in this study, the fertilizer application alternatives were classified into three groups.

Uniform application is the base technology used in this model. Historically, the majority of the crop land has had fertilizer applied with this application technique. The
uniform technology defined is one rate of fertilizer that is prescribed for the entire field, and it is based off a combination or any individual one of the following: composite soil sampling, farmer’s knowledge, farmer’s history, neighbor representatives, county average soil test, or recommendation from an industry consultant without a soil test. The main benefit of uniform application is that it is perceived to be the cheapest practice since no additional investment for variable rate application will be accrued, but the social costs are immense. Due to changes in soil characteristics, topography, drainage, and previous crops, one soil sample for an entire field does not accurately portray what is actually happening in the field. In summary, this application is the easiest to adopt, but farmers are being barraged by private and public entities that explain there are better ways to economically gather more accurate data, which will result in a more profitable investment in fertilizer application in the future.

The second technology is variable-rate application using grid soil sample data. For this technology, a soil sample is taken in a systemic but not necessarily square grid within the field. Grid sizes vary anywhere from a half an acre grid to ten or more acre-sized grids. Grid size should be dense enough to reveal the nutrient availability patterns in the field. There has been considerable research in the area of which size of grid will give the farmer the most accurate results while still being economical enough to adopt, but for the purpose of this research, we will classify all various sizes of grid methods into one group of variable-rate technology with a grid soil sample. A benefit of this technology is more data are collected and more samples are gathered which frequently lead to more information about the field. The problem with the adoption of grid soil sampling is the additional cost,
the economic limits of sample density, and consequently, the reliability of less dense grids and the limited time for soil sampling.

The third technology is variable-rate application using a management zone approach. For this technology, satellite imagery, yield maps, soil electrical conductivity sensors, soil surveys, aerial photos of growing crops and bare soil, and topography are used to create “like” zones within the field which have relatively the same production. With the field split into “production” zones, the farmer will then choose to take a minimal amount of soil samples within each zone so that each zone has a soil analysis associated with it to use in a variable-rate recommendation. This research emphasizes the use of satellite imagery as one input in the creation of the management zones. This technology is the newest of the three technologies, and within the past five years, satellite vendors have decreased imagery costs immensely so that the use of imagery is becoming more cost effective. The problem in using this technology is the added risk of relying on cloud-free days for satellite imagery acquisition, and if standard algorithms are not used, then subjectiveness could become a growing risk of this application.

The choice of uniform fertilizer application (base technology) is made outside of the framework of the model, so then the probability of selecting the base technology is indeterminate. This indeterminate problem can be overcome by normalizing the $\beta_0$ (the coefficients for flat rate application) to zero (Amemiya and Nold, 1975). Once this is done, the probability of the $i$-th production method by the $j$-th farmer is

$$\Pr_{ij} = \frac{e^{x_{ij}\beta_i}}{\sum_i e^{x_{ij}\beta_i}}.$$
Since profit is the main factor in the farmer’s production system, a farmer might choose the cheapest fertilizer application method which would be uniform rate, but due to the risk of over or under fertilization, the uniform-rate application might not meet the field’s production potential.

Marginal effects were also determined with this model framework as shown in Equation 4. The set of parameters $\beta$ reflects the changes in $X$ on the probability. The results of Equation 4 presents the effects a variation in the independent variable has on the probability of adopting variable-rate technology.

$$\frac{\partial P_j}{\partial X_{km}} = (1 - P_m)P_j\beta_k$$ (4)

Social risks are becoming more transparent. There will be an increase in adverse news reports on pollution of the rivers by non-point pollution, and since farmers are being signaled as a large culprit in this problem, farmers’ fertilizer practices will be in the spotlight. Education of variable-rate technologies application which are proven to apply fertilizer where the crop will use it more effectively will be crucial in showing farmers who currently apply fertilizer as a uniform rate that there are other alternatives to their current practice which are more environmentally friendly and profitable.

**Survey Procedure and Data**

The data for this analysis were not readily available, so a survey was created and sent out to farmers in the study area of Minnesota, North Dakota, and northern South Dakota. Farmers that were contacted were selected randomly from a precision agriculture
consulting business list. Farmers on the list were selected by the precision agriculture consulting business due to their location, as current customers, or as potential customers of precision agriculture equipment. The following is defined as precision agriculture technology: yield monitors (grain monitors that are installed on combines to measure the harvest yield), global positioning systems (GPS) receivers (systems that determine a latitude and longitude position), and lightbars (guidance system) or purchased consultation on their fields (i.e., yield mapping generation and analysis, variable-rate fertilizer application maps creation, and/or crop scouting). Within this sample, there is a representation of farmers who have adopted variable-rate technology and farmers who have not adopted variable-rate technology.

This list was then queried out to include just farmers who farm in North Dakota, Minnesota, and/or South Dakota. The geographical query of “farming only within the tri-State area” was first derived from the farmer’s mailing address. Personal knowledge was used since the author has consulted for 40-50 percent of these farmers. Once the returned surveys were aggregated, another query of only land location in North Dakota, Minnesota, and northern South Dakota was completed.

A survey was created with three main sections: demographic characteristics, farm and production data, and precision agriculture technology information. Within the precision agriculture technology section, information was collected on how they currently use precision agriculture technology or if he/she plans to implement precision agriculture technology in the future and his/her thoughts on environmental-based government programs. In creating this survey, recommendations were gathered from three sources. The main source of information was gathered from experts in academia who have had
extensive experience in collecting information and designing surveys. Recommendations were also gathered from personal contacts who interact with farmers on a daily basis in their agronomy positions with grain and fertilizer companies. The author’s personal experience in filling out the Census of Agriculture was also utilized.

Within the demographics section, seven questions were asked: age of the farmer, number of years the farmer has been employed in farming, geographic county information supplied by asking the farmer’s land location, the number of total acres, and percentage of owned versus rented land the farmer has in his/her farming operation. Three additional questions were asked where the farmers could select a choice or submit another answer if their choice was not supplied. The farmer’s level of education was requested using the following scale: (1) less than high school, (2) high school diploma, (2) some college, (4) college degree, and (5) post-doctoral degree. Information on which soil texture types the farmer has in his/her fields was also requested. Six selections were supplied: (1) clay, (2) silty clay, (3) silty clay loam, (4) loam, (5) sand, and (6) other (please specify). The type of crop rotation the farmer utilizes in his/her operation was also collected with four supplied answers and one other (please specify) crop rotation option. The following five options were supplied: (1) soybean, wheat, sugar beet, corn rotation; (2) soybean, wheat, corn rotation; (3) soybean, corn rotation; (4) soybean, barley, oil seed rotation; and (5) other (please specify).

Farm and production information was collected in section two of the survey. Crop-specific information was collected, including the acreage, average yield, and average price for the crop the farmer receives. Labor information on how many employees including the farmer was also collected. This information was split into five seasonal time frames for
ease of filling out the survey and to determine if labor is a limiting factor during different times throughout the growing season. The five time frames were winter, spring planting, summer spraying/cultivating, and harvest. Additionally, the harvest time frame was split into two other time frames, the “regular” harvest and the sugar beet harvest. Sugar beet harvest in the Red River Valley is a very intense, 24 hours per day, 7 to 14-day time frame. Assuming this type of harvest would possibly skew the typical “regular” grain harvest, the two classifications of harvest were used. Financial information was collected on the farm’s total value of farm assets broken into six ranges following USDA’s ranges: (1) < $200,000; (2) $200,000 to $499,999; (3) $500,000 to $999,999; (4) $1,000,000 to $1,999,999; (5) $2,000,000 to $4,999,999; and (6) ≥ $5,000,000. Estimated net worth of the farm operation was defined as assets minus liabilities. Again, six ranges were supplied for the farmer: (1) < $100,000; (2) $100,000 to $249,999; (3) $250,000 to $499,999; (4) $500,000 to $999,999; (5) $1,000,000 to $2,499,999; and (6) ≥ $2,500,000.

The final section of the survey was focused around precision agriculture technology. Information was collected on which fertilizer technology the farmer uses on his/her farm. The choices in technology were split into the three categories: uniform application, grid soil variable-rate application, and management zone (satellite based) variable-rate application. For each of these fertilizer applications, information was collected on the number of acres the technology was applied on, the mapping and data collection cost on a per-acre basis, and the charge of a custom application charge on a per-acre basis if the fertilizer was applied by a custom applicator.

Additional information was collected on the dollar amount of the farmer’s total investment in precision agriculture equipment and which precision agriculture equipment
the farmer invested in. Five options were (1) gps/lightbar (global positioning system and or lightbar that is used for guidance), (2) yield monitor (used to collect harvest information), (3) auto-steer (a new technology in which the tractor is guided by a global positioning system), (4) variable-rate controller (used to vary fertilizer/chemical application on the go), and (5) other (please specify).

Data were also collected on which year the farmer adopted variable-rate fertilizer technology and what mode of application the farmer uses, custom applied or self-applied. The definition of application mode is how the farmer applies the fertilizer on his/her field. Self application is when the farmer owns the equipment to apply the fertilizer himself/herself. Custom application is when the farmer does not own the equipment or have time to apply fertilizer, so a company that specializes in the precision agriculture business is paid to apply the fertilizer. This information was gathered to see if application equipment purchases might be a possible barrier to adopting precision agriculture.

The number of visits per year the farmer receives from a consultant who sells precision agriculture, and more specifically variable-rate fertilizer products like the ones described in this survey was asked. The question specified sales consultant visit and not an Extension visit because Extension personnel rarely visit farms for precision agriculture purposes unless invited.

Traditionally, the form of education has been provided by Extension conferences on precision agriculture, county meetings, circular courses at universities, and university news releases. Currently, private industry has begun educating farms through publications which have highlighted technologies and advertisements for new precision agriculture technologies. To measure the effect of the private industry form of education (sales and
training), the question was asked how many precision agriculture advertisements or technical articles in a newspaper or magazine has the farmer responded to or asked for more information.

The remainder of the precision agriculture technology section dealt with the 2002 Farm Bill. A binary choice question was asked if the farmer was aware of provisions for precision agriculture in the Farm Bill. Following the question was this explanation for clarity: “Section 2001 of the 2002 Farm Bill is the Conservation Security Program (CSP), established for fiscal years 2003 through 2007 to assist producers in implementing conservation practices to each operation and rewarding stewardship on working agricultural lands.” The next binary choice question asked if the farmer was currently enrolled in EQIP. Again, this question followed with an explanation of EQIP: “The Environmental Quality Incentives Program (EQIP) is a voluntary program that provides assistance to farmers and ranchers who face threats to soil, water, air, and related natural resources on their land.” This was followed up with a fill-in-the-blank question asking if the farmer was not enrolled in the program and why he/she was not. This question was to determine if the farmer chose not to enroll, was not eligible for the program (since EQIP money has been focused mainly to livestock and grain farmers), or if there were other reasons. The last question asked if the farmer would be interested in a similar program for grain farmers (this is referring to the new agri-environmental Conservation Security Program in the 2002 Farm Bill).

Lastly, the farmers were asked for what reasons would they use variable-rate technology. Three options were supplied with an additional (other, please specify) option.
The three options were environmental benefits, profitability, and recommendations from consultants, the university, and Extension agents.

The end of the survey thanked the farmer for responding to this survey and asked them to supply their address if they were interested in a copy of the research report.

Survey Pretest and Administering the Survey

After the initial design of the survey was created, a pretest was given to three farmers who were of varying farm size, and education levels and different locations. The goal of the pretest was to determine how much time the survey took and if there was any confusion created on specific questions. The pretest group took an average of 10 minutes to complete the survey and gave comments on questions which needed clarity and were used to edit the final version of the survey. Suggestions and questions from the pretest group were the following: The first iteration of the survey did not include the soybean, wheat, and corn rotation, so this alternative was added to the crop rotation area since 66 percent of the test group added this rotation into the “other” rotation. In the farm and production data area, “average yield” replaced “yield” since this led to confusion on whether the survey was asking for last year’s yield or average yield. Also, in the description for yield and price/acre, the sugarbeet terminology was added which is tons per acre in yield and price per ton for revenue.

The time frame of the labor section was changed. Previously the survey asked for number of employees and hours worked during the following time frames: February 15 to March 31, April 1 to May 31, May 31 to August 1, August 1 to September 1, and September 1 to November 30. After pretesting, it was discovered that the farmer was too
worried about the months and not which activity of the production cycle the time frame
was to represent. Due to uncertainty as to what an average growing season is, it was very
difficult to find a definitive time frame for each season. The main point of this question
was to determine how much labor varies between the phases of the farmer’s year, and since
the sugarbeet harvest in the Red River Valley is an intense, high-labor harvest during a
short time frame, this harvest was separated from a traditional grain and oilseed harvest.
The following time frames were developed: winter, spring planting, summer
spraying/cultivating, harvest, and then sugarbeet harvest. In the precision agriculture
technology section, the table asking for information specific to each of the three
technologies was made simpler. The total investment in precision agriculture equipment
was moved into a separate question followed with what type of equipment the farmer
invested in, which led to more complete information.

More questions were added to the government and education section of this survey.
Since enrollment had not happened yet for the CSP, assumptions were that the farmers
would not know about this program, and the question was changed to whether the farmer
was aware of the provisions for precision agriculture. Also, to help gauge the possible
enrollment in this government program, the farmer was asked if he/she is currently
enrolled in a similar program called EQIP. A description of each of the Farm Bill
programs was added for clarification since the test group did not fully understand each of
the programs.

An additional question was tagged at the end after the farmer understood the new
Farm Bill program and how it compared to an already successful environmental
conservation program; the question asked if the farmer was interested in a similar program
for grain farmers. A question was also suggested by one of the test group, who farms and
also consults for his own precision agriculture company, which asks if the farmer has ever
responded to a precision agriculture advertisement or technical article in a newspaper or
magazine. This question was added especially to account for the farmers who were
interested self starters and who did not have a current precision agriculture consultant
working for them.

The survey was mailed out to all 189 farmers on the business list. These 189
farmers were considered a representative pool of farmers in the Upper Midwest, and this
hypothesis is validated by the Financial Characteristics of North Dakota Farms 2000-
20002 report (Swenson). An introduction letter was included with the survey. This letter
introduced the reason for the survey and explained to the respondents how their names
were acquired. The letter and survey are included as Appendix A. An addressed stamped
envelope was also included for their ease in returning the completed survey. Three days
later, the first completed survey was received. Three weeks later, a thank you and
reminder postcard was sent out to 186 farmers since three surveys came back as non-
deliverable and personal reminders were given during business contact with the survey
farmers. A 36 percent return rate was achieved, and 62 percent of the farmers supplied
their address and stated they were interested in receiving the final research report. Within
Appendix C, there is a map showing the geographic location of the counties represented by
one or more farmers.
Data Management and Description of Variables

This next section clearly explains the data management procedure. When analyzing the data, it was clear that farmers utilize more than one fertilizer application technology on their farms. Seven combinations of the fertilizer application technology variables were found: uniform application, grid application, management zone application, combination of grid and uniform application, combination of uniform and management zone application, combination of grid and management zone application, and all (uniform, grid, and management zone) applications. Most of the combinations were farmers who were experimenting with the technologies (trials) based on the number of acres under each technology.

A precision agriculture sales consultant will rarely sell a new technology for the farmer’s entire farm. This could be due to the “let’s try it” approach and also due to the rotation of crops; certain fields may not have the correct crop rotation to implement the new technology. It could also be that some fields are variable in some years while others are not, and some landlords are responsive to new methods and some are not. Overall, classifying the “all alternative technologies combinations” into a trial stage avoided the problem of mutually exclusive choices.

Technology variable zero represents when the farmer listed he/she used all technologies and this is labeled the trial stage. Technology variable one is the uniform technology which is the base technology. Technology variable two is grid, and technology variable three is the management zone technology. The marginal impact of the major factors was consistent across the board, indicating results or main conclusions did not change significantly due to the representation into four major categories. Also, this
representation, shown in Figure 3, provided a significant number of observations in each category for the econometric analysis.

![Pie chart](image.png)

Figure 3. Distribution of the survey farmer’s choice of fertilizer application technology.

Variables were also combined for the crop rotations question within the demographic characteristics section. This question listed four main crop rotations, but another option (other, please specify) was also listed. The four crop rotations that were given were variable one (represents the soybean, wheat, sugar beet, and corn rotation), variable two (soybean, wheat, and corn rotation), variable three (soybean and corn rotation), and variable four (soybean, barley, and oil seed rotation).
CHAPTER 4. RESULTS

Survey Results

Farmers who filled out the survey had an average education of some college; the minimal education was a high school diploma with a few farmers who had achieved graduate degrees. The average farmer in the pool adopted precision agriculture technology in 1997. Ninety-seven percent of the farmers stated profitability is a reason they will use or plan to use variable-rate fertilizer technology. Sixty-three percent of the farmers included environmental benefits as their reason for adopting precision agriculture, and 35 percent of the farmers included recommendations from sales consultants or university or Extension agents as the reason they have or plan to use variable-rate fertilizer technology. Other answers included cost effectiveness and easy application and delivery of product. A few farmers responded that they will not implement variable rate technology because they cannot justify the costs and there is no return on investment.

There was a wide range in leverage ratio among respondents. Farmers in the research sample had leverage ratios ranging from 1 to 8.33. The maximum value indicates much larger assets compared to their net worth, indicating that their farms had more cost constraints.

Table 1 presents a list of the main crops grown by the respondents: canola, sweet corn, peas, potatoes, alfalfa, edible beans, sunflowers, durum, and flax.

Within the precision agriculture technology section of the survey, a binary choice question was asked if the farmer was interested in the new conservation security program. Eighty-one percent said yes, they are interested in the conservation security program and will enroll in it. One represented yes to the question, two is the reply no, and then the
farmers who did not answer this question were assigned variable three (representing, “I don’t know”).

Table 1. Distribution of Crops Grown by Respondents

<table>
<thead>
<tr>
<th></th>
<th>Average Acres/Farmer</th>
<th>Yield/Acre</th>
<th>Price</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn</td>
<td>863.66</td>
<td>150.93</td>
<td>$2.26</td>
<td>44</td>
</tr>
<tr>
<td>Soybeans</td>
<td>861.72</td>
<td>40.54</td>
<td>$5.47</td>
<td>58</td>
</tr>
<tr>
<td>Wheat</td>
<td>994.03</td>
<td>41.45</td>
<td>$4.01</td>
<td>7</td>
</tr>
<tr>
<td>Barley</td>
<td>445.00</td>
<td>55.71</td>
<td>$2.89</td>
<td>37</td>
</tr>
<tr>
<td>Sugarbeets*</td>
<td>768.35</td>
<td>19.81</td>
<td>$37.14</td>
<td>23</td>
</tr>
</tbody>
</table>

Averages of farmers who included the specific crop in their rotation. In per ton or per bushel measurements.
* Corn, soybean, wheat, barley in bu/A; sugarbeet in ton/A. Corn, soybean, wheat, barley in $/bu; sugarbeet in $/ton.

Thirty-one percent of the farmers had followed up on a precision agriculture advertisement or technical article in a newspaper or magazine and with an average of 2.5 times per year.

Thirty-six percent of the farmers apply their fertilizer themselves, 51 percent have their fields custom applied, and another 13 percent of farmers responded they use both modes of applications within their farming operation. Figure 4 shows the average cost per acre for each fertilizer technology. Traditionally the uniform-rate technology application cost per acre is less expensive than the grid technology application per acre and management zone cost per acre. In this study, the uniform cost per acre was $4.88/A, the grid technology cost per acre was $11.04/A, and the management zone cost per acre was $10.12/A. The costs listed previously are only the map technology cost and application costs; these costs do not include the actual tons of fertilizer used. One would assume the usage of fertilizer for the grid and management zone technology would be less than the
uniform tons per acre. Especially since more information is utilized in creating the management zone and grid maps, the fertilizer is used more efficiently. This might compensate for the high application cost for grid and management zone.

![Figure 4. Average cost per acre for each fertilizer technology.](image)

In addition to taking time to fill out this survey, farmers also wrote personal comments. Some explained with a paragraph on what exactly their method of fertilizer application is or which techniques they implement and why they came to the decision of choosing that variable rate technology. For example, one farmer stated he/she chose a variable-rate fertilizer program since he/she had a lot of variable soil types. Also, there were explanations of why the farmer stopped using the variable-rate technology on his/her farm, if any. Cost was usually the major limitation. Within the level of education question, farmers wrote short notes on receiving a masters degree in agriculture economics. Farmers also listed a wide range equipment he/she had invested in. Farmers listed hand-
held computers, laptops, handheld gps units, and RTK machines (measures topography precisely) in the supplied other (please specify) answer. Summary statistics of the data are presented in Table 2.

Table 2. Descriptive Statistics of Data

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observations</td>
<td>67</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age (Years)</td>
<td>45</td>
<td>23</td>
<td>67</td>
<td>9.12</td>
</tr>
<tr>
<td>Years in Farming</td>
<td>23</td>
<td>4</td>
<td>47</td>
<td>9.39</td>
</tr>
<tr>
<td>Acres Farmed</td>
<td>2599</td>
<td>54</td>
<td>15000</td>
<td>2538.44</td>
</tr>
<tr>
<td>Acres Owned</td>
<td>973</td>
<td>0</td>
<td>6000</td>
<td>1255.56</td>
</tr>
<tr>
<td>Acres Rented</td>
<td>1628</td>
<td>0</td>
<td>9000</td>
<td>1665.49</td>
</tr>
<tr>
<td>Acres of Flat</td>
<td>1780</td>
<td>54</td>
<td>15000</td>
<td>2519.08</td>
</tr>
<tr>
<td>Grid</td>
<td>503</td>
<td>40</td>
<td>2200</td>
<td>636.97</td>
</tr>
<tr>
<td>Management Zone</td>
<td>897</td>
<td>40</td>
<td>6500</td>
<td>1380.94</td>
</tr>
<tr>
<td>Invested in P.A.</td>
<td>$15,032</td>
<td>$375</td>
<td>$75,000</td>
<td>$17,204</td>
</tr>
<tr>
<td>% of Farmers Invest in P.A.</td>
<td></td>
<td></td>
<td></td>
<td>68%</td>
</tr>
<tr>
<td>Net Worth</td>
<td>$500,000 to $999,999</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Financial Leverage</td>
<td>1.08</td>
<td>0</td>
<td>8.33</td>
<td>1.64</td>
</tr>
<tr>
<td>Sales Visits/Year</td>
<td>3.17</td>
<td>0</td>
<td>45</td>
<td>0.94</td>
</tr>
<tr>
<td>Labor Season</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full Time Employees (including the Farmers)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Winter</td>
<td>2.3</td>
<td></td>
<td></td>
<td>41.25</td>
</tr>
<tr>
<td>Spring</td>
<td>3.1</td>
<td></td>
<td></td>
<td>70.6</td>
</tr>
<tr>
<td>Summer</td>
<td>3.0</td>
<td></td>
<td></td>
<td>60.1</td>
</tr>
<tr>
<td>Harvest</td>
<td>4.5</td>
<td></td>
<td></td>
<td>75.7</td>
</tr>
<tr>
<td>Sugarbeet Harvest</td>
<td>7.6</td>
<td></td>
<td></td>
<td>85.6</td>
</tr>
</tbody>
</table>

Empirical Model and Econometric Estimation

Limdep Econometric software was used to estimate the multinomial logit model.

The model includes the intercept since after running iteration without the intercept, it was
noticed that the robustness of the model did not change, defined by the $R^2$, percent correct prediction, and the number of significant variables in the model. Alternative model results are found in Appendix B.

Multicollinearity relationships were noticed in the output of the model. A correlation matrix was created to find the relationships between the variables and to determine which variables were to be used in the model. The technology cost variable and the technology group variable had .97 correlation, so the technology cost variable was not included in the model.

Corn and soybean yield had a .78 correlation which could be explained by the fact that high-producing soils will produce high-yielding corn and soybeans. Corn yield and corn revenue were correlated .91 since revenue was determined with yield as a factor, and this was also the case for soybean yield and soybean revenue and the other crops and their respective revenues. Total acres farmed by the farmer and acres rented had a .90 correlation. Total acres farmed also had a .82 correlation with acres rented. Age of the farmer and the number of years the farmer farmed had a .88 correlation. The variable years farmed was used in the model instead of age of the farmer. Traditional explanation for the difference in adoption behavior among farms often points to factors such as farm size, farmer education and age, farm tenure, attitudes toward risk, and other characteristics of the farm operator (Daberkow and McBride, 1999). Previous research often states the age of the farm operator is significant; however, this variable was not significant in trial models and did not affect the robustness of the model either.
Multinomial Logit Results

The multinomial model had the fertilizer application variable as the dependent variable and sales visits, total acres, years farmed, education level, net worth, financial leverage, soil type, crop rotation, land location, and planned enrollment in government agri-environmental programs as independent variables.

The percentage of correct predictions is calculated as the total number of correct predictions of the number of observations, and this model resulted in 62.12 percent correct predictions. The chi-squared value was 226.24 with a significant probability (chi sqd > value) = 0.0000.

To test the robustness of the model, choice-based sampling was applied. The coefficients are not affected, but the estimation errors are minimized with this procedure. Greene (2003) stated that this procedure adjusts the estimated asymptotic covariance matrix for possible misspecification in the model which leaves the MLE consistent. Mathematically this is presented in Equation 5.

\[
\text{Est. Asy.Var} [\hat{\beta}] = \left[ \sum_{i=1}^{n} \left( \frac{\partial^{2} \log F_{i}}{\partial \beta \partial \beta'} \right) \right]^{-1} \left[ \sum_{i=1}^{n} \left( \frac{\partial \log F_{i}}{\partial \beta} \left( \frac{\partial \log F_{i}}{\partial \beta'} \right) \right) \right] \left[ \sum_{i=1}^{n} \left( \frac{\partial^{2} \log F_{i}}{\partial \beta \partial \beta'} \right) \right]^{-1} 
\]

The results for the multinomial logit model are reported in Table 3.

The p-value is used to determine if the variable is significant. The p-value is when the standard normal probability of N [0, 1] is greater than or equal to the ratio of the estimated variable to the variable’s estimated standard error (Greene, 2003). A p-value of 0.01 is reporting that the variable is very significant at the 1 percent level, 0.05 has less significance, and 0.10 has the least significance of the three levels but is still a significant
variable at the 10 percent level. After establishing the significance of the variable, then the focus moves to whether the variable had a negative or positive effect on the probability of adopting precision agriculture technology.

For the farmers who have not adopted variable-rate fertilizer technology and only use uniform fertilizer application, government programs, financial leverage, years the farmer has farmed, formal education of the farmer, and soil type were significant at the 0.01 probability level. Total acres the farmer has in his/her operation were significant at the 0.05 probability level, and sales and training were significant at the 0.10 probability level.

Within the technology group of farmers who have implemented grid variable-rate technology in their programs, ten of the eleven variables were significant. Sales and training by precision agriculture private consultants, interest in enrolling in the CSP agricultural environmental government program, financial leverage, total acres the farmer farms, years the farmer has farmed, formal education of the farmer, and soil type are significant at the 0.01 probability level. The farmer’s net worth and land location were significant at the 0.05 probability level.

For the farmers in the management zone technology group, nine of the eleven variables were significant at the 0.01 probability level. Sales and training, government programs, net worth, financial leverage, years farmed, formal education of the farmer, soil type, and land location were the variables that were significant at the 0.01 probability level.

Soil type positively impacts the farmer’s decision on whether to adopt variable-rate technology. There are numerous explanations, but ideally, the farmer is aware of his/her soil types and is trying to implement a production practice that will use the knowledge of
these soil types as a factor in determining the correct fertilizer rates for the field’s yield potential.

The number of years the farmer has farmed negatively impacts the farmer’s decision to adopt more variable-rate technology. This could be referring to the farmers who have farmed for many years and have been successful thus far so are not planning to incur any costs in contrast to a younger farmer who is still progressively experimenting in production practices which could work for his/her operation.

Net worth positively impacts the farmers who currently implement management zone technology in their operation on whether they will adopt more technology. This positive impact by net worth is showing the profitability of the venture of using management zone technology within the operation, and then the increase in profitability adds to net worth.

Land location had a negative impact on the adoption of management zone. The negative impact of land location is explained by remote locations which are farther away from a regional center where the adoption has occurred or the necessary equipment is available.

Table 3 shows how important sales visits by precision agriculture consultants are in determining what methods impact the farmer’s decision on choice of fertilizer application technology. These visits create a negative impact on the farmer’s decision to adopt variable-rate application technology or to adopt more variable-rate application technology. This is suggesting that with more visits from precision agriculture consultants, fewer farmers adopt variable-rate precision agriculture technology. It is possible that farmers view consultants as profit seekers. In the survey group, 41 percent of the farmers replied
they have received a sales visit from a precision agriculture consultant with an average of three visits per year. Again, this suggests possible deviations and retaliation from the one-stop adoption process.

Table 3 points out that enrollment in government programs had a negative impact on all farmers who use uniform, grid, or management zone fertilizer technologies in their operation. However, government programs significantly and negatively affected the farmers who have already adopted the management zone technology on their adoption of more variable-rate technology. The data collection survey did ask the farmers if they were interested in an agri-environmental program that is similar to EQIP but for grain farmers; 81 percent of the farmers replied they were interested in this program.

The negative effect of the government programs could be explained by the comments farmers wrote. The following comments came from a question that asked the farmers why they were not enrolled in EQIP. It was assumed when creating this question that farmers would answer along the lines of how they were not eligible for the government program or there was limited funding for the county. Instead, 69 percent answered they did not know about the program, were “not aware of the program,” or “didn’t realize it was there.”

An additional 14 percent mentioned specifically that their “county doesn’t seem to know the rules yet” or “they are not ready for us to sign up yet,” and 11 percent of the responses were directed towards their beliefs in enrollment in government programs. “Too much red tape,” “do not like government intervention,” “too much hassle for what I get,” and “not enough dollar incentive” were sample responses.
Table 3. Results of Multinomial Logit Model
Characteristics in Numerator of Probability (Uniform)

| Variable                      | Coefficient | Standard Error | P[|Z|>|z|] | Mean of X |
|-------------------------------|-------------|----------------|----------|-----------|
| Sales and Training            | -1.0076     | 0.5399         | 0.0620   | 3.1742    |
| Government Program            | -1.7369     | 0.4346         | 0.0001   | 1.6061    |
| Net Worth                     | 0.3488      | 0.2758         | 0.2060   | 3.9394    |
| Leverage                      | 1.1812      | 0.2550         | 0.0000   | 1.0780    |
| Government/Sales*             | 0.1659      | 0.2943         | 0.5730   | 4.5076    |
| Total Acres                   | 0.0004      | 0.0002         | 0.0220   | 2579.9242 |
| Years Farmed                  | -0.0666     | 0.0211         | 0.0016   | 23.3788   |
| Education                     | 1.0664      | 0.1918         | 0.0000   | 3.4242    |
| Soil Type                     | 0.2783      | 0.0545         | 0.0000   | 7.6515    |
| Crop Rotation                 | -0.0154     | 0.2059         | 0.9404   | 4.0606    |
| Land Location                 | -0.0150     | 0.0167         | 0.3681   | 27.2727   |

Characteristics in Numerator of Probability (Grid)

| Variable                      | Coefficient | Standard Error | P[|Z|>|z|] |
|-------------------------------|-------------|----------------|--------|
| Sales and Training            | -1.4891     | 0.3813         | 0.0001 |
| Government Program            | -2.2320     | 0.4860         | 0.0000 |
| Net Worth                     | 0.7726      | 0.3493         | 0.0270 |
| Leverage                      | 1.5924      | 0.2719         | 0.0000 |
| Government/Sales*             | 0.6025      | 0.2009         | 0.0027 |
| Total Acres                   | -0.0005     | 0.0002         | 0.0095 |
| Years Farmed                  | -0.0936     | 0.0324         | 0.0038 |
| Education                     | 0.8245      | 0.2749         | 0.0027 |
| Soil Type                     | 0.3009      | 0.0563         | 0.0000 |
| Crop Rotation                 | 0.2728      | 0.0202         | 0.1769 |
| Land Location                 | -0.0425     | 0.0190         | 0.0252 |

Characteristics in Numerator of Probability (Management Zone)

| Variable                      | Coefficient | Standard Error | P[|Z|>|z|] |
|-------------------------------|-------------|----------------|--------|
| Sales and Training            | -0.5012     | 0.0896         | 0.0000 |
| Government Program            | -3.0759     | 0.5295         | 0.0000 |
| Net Worth                     | 1.1933      | 0.3219         | 0.0002 |
| Leverage                      | 1.1027      | 0.2723         | 0.0001 |
| Government/Sales*             | 0.1755      | 0.0590         | 0.0029 |
| Total Acres                   | 0.0002      | 0.0002         | 0.1467 |
| Years Farmed                  | -0.0889     | 0.0254         | 0.0005 |
| Education                     | 0.8647      | 0.2049         | 0.0000 |
| Soil Type                     | 0.2261      | 0.0486         | 0.0000 |
| Crop Rotation                 | 0.1549      | 0.2108         | 0.4624 |
| Land Location                 | -0.0682     | 0.0178         | 0.0001 |

* Government/Sales variable represents the combined-effect of government programs and sales and training.
The stated hypothesis, “farmers perceive the new agri-environmental government programs to enhance the adoption of precision agriculture technology,” was rejected based on the results found in Table 3. First, for the farmers who are in the technology group who have not adopted variable-rate technology and use uniform fertilizer technology, government programs are very significant and negatively affect the adoption of variable-rate technology, thus not validating this hypothesis. One possible explanation may be that farmers do not directly perceive the benefits of government programs because of deviations from the traditional one-stop shopping. In addition, sales visits (training and education) had a negative and significant impact on the adoption of variable-rate fertilizer technology.

Also, for farmers who had adopted grid variable-rate fertilizer technology in their operation, government programs had a very significant and negative effect on the further adoption of precision agriculture technology. Sales and training also had a very significant and negative effect on the adoption of precision agriculture technology for this group of farmers.

Within the third technology group, which was the farmers who had adopted management zone variable-rate technology in their fertilizer program, government programs and training and sales variables had a very significant and negative impact on the further adoption of precision agriculture technology. One possible explanation may be that this group of farmers is beginning to perceive the relative lower cost of this technology compared to grid (Figure 4).

In order to understand how each of the independent variables impacted the results of the model, we should study the marginal probability of the variable.
As previously stated, due to the potential wide acceptance of the new Conservation Security Program in the 2002 Farm Bill and limited NRCS personnel, the NRCS is looking to certified personnel from the private sector to help the farmers implement production practices that will enable them to be rewarded with government payments. Thus far, the interaction between the farmers and the precision agriculture sales consultant has been as a client/customer or consulting education relationship. Historically, the farmer is paying the sales consultant for knowledge services and equipment that the farmer has been taught will help him become more profitable. As previously stated, the adoption of precision agriculture technology has been rather slow and often stagnant after some time. With the private industry conducting a majority of the precision agriculture research due to limited funding in the public arena, private research will mainly be positive and help promote the new technologies; however, the farmers seem reluctant to adopt precision agriculture technology or they do not seem to believe the private industry research results.

In this model, the interaction between the farmer and the private industry sales consultant is measured by the sales visit independent variable, and this variable negatively and significantly affected the farmer’s adoption of precision agriculture.

To further back up the above claims, a combined-effect variable was added to the list of independent variables in the model. The robustness of the model was not affected, and the previous model output results without the combined-effect variable can be found in Appendix B. The combined-effect variable was created using the government programs variable multiplied by the sales visits from private precision agriculture sales personnel. The results of this combined-effect variable (government/sales) can be found in Table 3. This variable was not significant for the farmers who had not adopted variable-rate
fertilizer technology (uniform group); the variable was significant at the 0.01 probability level and had a positive effect for the farmers who had adopted grid variable-rate fertilizer technology in their operation. The combined-effect variable of government programs and sales visits was also significant at the 0.01 probability level and positive for the group of farmers who use the management zone variable-rate technology in their operation.

The positive significant effect of the combined-effect variable of government programs and sales in training, varies from the previous significant negative impact from each variable individually on the adoption of precision agriculture technology. This converse effect suggests the need for policy changes within the program.

**Marginal Impacts**

The marginal impacts of selected variables averaged over individuals on the probability of adopting variable-rate fertilizer precision agriculture technology that will enable us to answer the main objective of the study are found in Table 5.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Trial (0)</th>
<th>Uniform (1)</th>
<th>Grid (2)</th>
<th>Management Zone (3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sales and Training</td>
<td>0.0549</td>
<td>-0.0410</td>
<td>-0.0710</td>
<td>0.0584</td>
</tr>
<tr>
<td>Total Acres</td>
<td>0.0000</td>
<td>0.0001</td>
<td>0.0000</td>
<td>0.0000</td>
</tr>
<tr>
<td>Years Farmed</td>
<td>0.0049</td>
<td>0.0015</td>
<td>-0.0020</td>
<td>-0.0030</td>
</tr>
<tr>
<td>Education</td>
<td>-0.0580</td>
<td>0.0603</td>
<td>-0.0060</td>
<td>0.0048</td>
</tr>
<tr>
<td>Net Worth</td>
<td>-0.0450</td>
<td>-0.0840</td>
<td>0.0202</td>
<td>0.1093</td>
</tr>
<tr>
<td>Leverage</td>
<td>-0.0740</td>
<td>0.0157</td>
<td>0.0541</td>
<td>0.0052</td>
</tr>
<tr>
<td>Soil Type</td>
<td>-0.0160</td>
<td>0.0108</td>
<td>0.0065</td>
<td>-0.0010</td>
</tr>
<tr>
<td>Crop Rotation</td>
<td>-0.0060</td>
<td>-0.0310</td>
<td>0.0228</td>
<td>0.0142</td>
</tr>
<tr>
<td>Government Program</td>
<td>0.1429</td>
<td>0.0900</td>
<td>-0.0270</td>
<td>-0.2060</td>
</tr>
<tr>
<td>Land Location</td>
<td>0.0024</td>
<td>0.0055</td>
<td>-0.0010</td>
<td>-0.0060</td>
</tr>
<tr>
<td>Government/Sales*</td>
<td>-0.0140</td>
<td>-0.0210</td>
<td>0.0437</td>
<td>-0.0070</td>
</tr>
</tbody>
</table>

* Government/Sales variable represents the combined-effect of government programs and sales and training.
An interesting research question is “what is the marginal impact of education (sales training) on the adoption of precision agriculture?” The answer to this question is known when viewing the results of the uniform technology group in Figure 5. The farmers who have not already incorporated variable-rate technology within their operation are prime targets for the agri-enviromental programs. Figure 5 shows that with increasing sales visits by the precision agriculture private industry, the probability of the farmers adopting grid technology will decrease.

On the other hand, for the farmers who have already adopted a variable-rate technology, for example management zone variable-rate, an increase in sales visits by precision agriculture personnel led to an increase in the adoption of more precision agriculture technology. The results suggest intensifying training needs with experimental trial plots for management zone technology.

![Figure 5. Probability of adoption as a function of sales visits.](image)

Education in the form of sales visits by the private industry has a negative effect on the adoption of precision agriculture technology for some groups of farmers. Another
research question is “how will the agri-environmental government programs affect the adoption of precision agriculture?” In answering this research question, government programs had a significant and negative impact on the farmers who are using the management zone technology within their operation. It is established that sales visits have a negative and significant effect on the farmers who have adopted the management zone variable-rate technology. One can conclude that an increase in sales visits by precision agriculture industry personnel, especially when the visit is for the farmer’s government program incentives, will turn off the farmer from adopting precision agriculture technology. Thus, enrolling in agri-environmental government programs will reduce the likelihood of farmers adopting variable-rate precision agriculture technology. This is possible due to deviations from the one-stop adoption process (Figure 1).

Financial leverage had a positive and significant impact on adopting new technology with the farmers who already use grid variable-rate technology in their operation. The more the farmer’s financial leverage ratio is close to 1, the more this will prompt the farmer to adopt more precision agriculture technology due to a small burden of debt. Also, net worth had a positive and significant impact on adopting more variable-rate technology on farmers who have adopted management zone variable-rate technology in their operation. This can be explained by the fact that the profitability of using management zone technology in the farmer’s operation will lead the farmer to adopt more profitable ventures that will add to the farmer’s net worth. Figure 6 shows that the higher the networth, the fewer the cost constraints and the higher the probability that the farmer will adopt variable-rate technology, especially management zone.
Figure 6. Probability of adoption as a function of net worth.
CHAPTER 5. CONCLUSION AND POLICY RECOMMENDATIONS

The state of the environment will be kept on everyone’s radar screen, especially with increasing concern for hypoxia and safe drinking water. The government has selected precision agriculture technology as a way to help manage natural resource concerns. Other research can focus on whether precision agriculture has enough long-term unbiased research and whether precision agriculture will help control natural resource concerns such as nonpoint pollution while still keeping the farmer profitable in the long run. This uses survey data collected from farmers in North Dakota, Minnesota, and South Dakota to analyze the impact of agri-environmental government programs on the adoption of precision agriculture, or variable-rate fertilizer technology. Again, let us refer to the changes in the flow of information between farmers and the government agencies that handle the sign-up of government programs shown previously in Figure 1. If the conduit for the information remains to be the private sector sales consultant between the government and the farmer, and if all things stay the same, these government programs will have a negative impact on the adoption of precision agriculture. The policy implications of this outcome are significant. It is recommended that the policy variable of education (sales visits by private precision agriculture sales personnel) be re-evaluated.

Precision agriculture technology is increasingly becoming a more manageable investment. Improvements in technology and cooperation between software, hardware, and equipment manufacturers are contributing to setting the stage for more customizable uses of this technology. In this study, questions were asked of how many of the farmers have invested in precision agriculture equipment. Sixty-eight percent of the farmers stated they have invested in precision agriculture equipment. Of these who have invested, there
was a range of investment of $375 to $75,000, with an average of $15,000. Acquisition of satellite imagery which can be used in many applications of precision agriculture technology is becoming a more manageable expense. Soil sensors and topography reading units are becoming cheaper and more available which, in turn, makes management zone variable rate application more enticing. Global positioning systems (used for applying variable-rate fertilizer and to gather necessary information for interpretation) used to be a large limitation on the availability of these variable-rate (grid and management zone) products to farmers, but global positioning systems are fairly reasonable in cost, and farmers are buying them for a variety of reasons, some for business and some for recreation.

With the decreased level in precision agriculture costs and the government trying to promote agri-environmental programs, one can say the time is right for the adoption of precision agriculture. Since the time is right for the adoption of precision agriculture, it is suggested that the government further tailor the government programs they are trying to implement. Tailoring these programs will ensure more success in adopting precision agriculture technology and thus protecting our environment. The basis of this recommendation is shown in this research; there are differential impacts of the government programs, education, and financial performance on farmers who have or have not adopted certain types of variable-rate fertilizer technologies.

Varying programs could be developed which focus on each specific technology group, and these programs will encompass the impact of education by private precision agriculture sales personnel or an increase in Extension education and encompass financial performance of the farmer and how they view agri-environmental programs.
Limitations of the Study

This sample group was limited to 189 farmers. A 34 percent return rate was achieved, but it is noted that data were a limitation in this model. As previously stated, the sample group for this survey is representative of the farmers of North Dakota and Minnesota. A survey of the 30,000 farmers in North Dakota and the 79,000 farmers in Minnesota would have been ideal, but due to limitations in resources, this was not achieved. The sample of these farmers is representative of the farmers in North Dakota pertaining to the Financial Characteristics of North Dakota Farms 2000-2002 (Swenson).

Future Perspectives

Recommendations for future research would be to transfer the experiment’s test area to other geographic areas. This will first explain whether the reaction to precision agriculture sales personnel is unique in the study area or is common along other agricultural-intensive areas. Another suggestion for a different type of geography would be where there has been no prior influence/experience of precision agriculture variable rate technology. This will help determine if the change in the flow of information within the government programs will negatively or positively impact the adoption of precision agriculture technology.

Also, creating another independent variable that represents the farmer gleaning information on precision agriculture technologies from university and Extension services (i.e., literature, conferences, and meetings) and how the farmer uses that information in his/her decision will be beneficial to this area of research.
Another recommendation for future research would be to transfer this experiment to a fragile geographic location where regulations have been set in place to limit nonpoint pollution, for example, the Chesapeake Bay. In 1987, the Chesapeake Bay Agreement was created in which the goal is to reduce the nutrients nitrogen and phosphorous entering the bay by 40 percent in 2000, and the Chesapeake Bay partners agreed to continue the goal of reduction beyond year 2000. This study area will show the impact a mandatory government program has on the adoption of precision agriculture technology.
REFERENCES CITED


____. “Bumpy road to Adoption of Precision Agriculture.” Purdue Agricultural Economics Report, Purdue University Cooperative Extension Service, November 1997.


APPENDIX A. SURVEY INSTRUMENT

Marginal Impact of Government Programs and Training on the Adoption of Precision Agriculture

A. Demographics Characteristics:

1. How old are you? __________ (Years)

2. How many years have you been farming? __________ (Years)

3. What is your level of education?
   _____ Less than high school     _____ High school diploma
   _____ Some college    _____ College degree
   _____ Post-doctoral degree

4. Land location: ________________________________County(s)

5. Please, specify your soil type(s).
   _____ Clay  _____ Silty Clay  _____ Silty Clay Loam  _____ Loam   _____ Sand
   _____ Other (please specify__________________)

6. What crop rotation do you practice?
   _____ Soybean, Wheat, Sugarbeet, Corn Rotation
   _____ Soybean, Wheat, Corn Rotation
   _____ Soybean, Corn Rotation
   _____ Soybean, Barley, Oil Seed Rotation
   _____ Other ________________________(please specify)

7. How many acres do you farm? __________ Acres
   __________% Owned   __________% Rented

B. Farm and Production Data:

1. For the following crops, please indicate the number of acres planted, yield per acre, and price per bushel received last year.

<table>
<thead>
<tr>
<th># of Acres</th>
<th>Average Yield (bu/ac, lbs/A, T/A)</th>
<th>Price/Bu (Price/Lb, Price/T)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soybeans</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wheat</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Barley</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sugarbeets</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other (____)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other (____)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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2. How many employees work on your farm, including yourself?

<table>
<thead>
<tr>
<th>Time frame</th>
<th>Full time</th>
<th># Hours per worker/week</th>
<th>Part time</th>
<th># Hours per worker/week</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winter</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spring Planting</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Summer</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spraying/Cultivating</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Harvest</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sugarbeet Harvest</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3. What is the estimated total value of all your farm assets?

- ________ <$ 200,000
- ________ $ 200,000 to $ 499,999
- ________ $ 500,000 to $ 999,999
- ________ $ 1,000,000 to $ 1,999,999
- ________ $ 2,000,000 to $ 4,999,999
- ________ ≥$ 5,000,000

4. Estimated net worth (assets – liabilities) of your farm operation:

- ________ <$ 100,000
- ________ $ 100,000 to $ 249,999
- ________ $ 250,000 to $ 499,999
- ________ $ 500,000 to $ 999,999
- ________ $ 1,000,000 to $ 2,499,999
- ________ ≥$ 2,500,000

C. Precision Agriculture Technology

Please indicate what type of fertilizer application you use, the number of acres for each type of application, the mapping and data collection cost per acre, and the custom application charge.

<table>
<thead>
<tr>
<th>Type of technology</th>
<th># of acres applied on</th>
<th>Mapping and data collection cost ($)</th>
<th>Custom application charge ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flat Rate Application</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grid Soil Variable Rate Application</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Management Zone Variable Rate Application (Satellite-based)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

57
1. Total investment in precision agriculture equipment? $____________________
   (Please check all equipments that apply to your investment)
   ___ GPS/Lightbar  ___Yield Monitor  ___ Auto-Steer
   ___Variable Rate Controller (Fertilizer/Chemical Application) ___Other

2. If you use variable-rate fertilizer technology, please indicate the year you adopted this technology. ______

3. What application mode do you use?  ____Self application  ____Custom applied

4. How many visits do you receive per year from a consultant who sells precision agriculture variable-rate fertilizer products like the ones mentioned above? ______ (Number/Year)

5. Have you responded to or followed up on a precision agriculture advertisement or technical article in a newspaper or magazine? ______(Number/Year)

6. Are you aware of provisions in the Farm Bill for precision agriculture?
   _____Yes _____No
   {Section 2001 of the 2002 Farm Bill is the Conservation Security Program (CSP), established for Fiscal Years 2003 through 2007 to assist producers in implementing conservation practices to each operation and rewarding stewardship on working agricultural lands.}

7. Are you enrolled in the EQIP program?  _____Yes  ______No
   {The Environmental Quality Incentives Program (EQIP) is a voluntary program that provides assistance to farmers and ranchers who face threats to soil, water, air, and related natural resources on their land.}

8. If no, why?_____________________________________________________

9. Are you interested in a similar program for producers of working lands (grain farmers)?  ___Yes ___No

10. Why would you use variable rate technology? (Check all that apply)
    _____Environmental benefits
    _____Profitability
    _____Recommendations from consultants, university, Extension
    _____Others (please specify ___________________________________)

Thank you for responding to this survey. If you would like a copy of my final report, please provide your address below.

Address:  Street _______________ City and State_______________ Zip _______
Introduction Letter

June 30, 2003

Dear Agricultural Producer:

Hello, my name is Mary Friedrichsen. I am currently a graduate student at North Dakota State University, and I am a consultant for Precision Partners, Inc.

While being involved with my family farm, I have realized there is often a disconnect between the government’s farm policy and what the farmer needs to be profitable.

I would appreciate you taking 10-15 minutes of your time to fill out this survey, which will help me complete my graduate degree.

My goal of this study is to identify factors that will facilitate the adoption of environmentally friendly precision agriculture technologies while the farmer remains profitable and the conservation initiatives of the 2002 Farm Bill are met.

Thank you, and if you have any questions, please feel free to call me at (xxx)xxx-xxxx.

Mary Friedrichsen

All information provided by the participants of this study will be held in the strictest confidential manner possible, and only aggregate data will be published to preserve the identity of individual farmers.
# APPENDIX B. SUPPLEMENT RESULTS

Table 6. Summary of Marginal Effects on Probability of Adopting Variable-Rate Fertilizer Technology

| Marginal Effects, Y= 0 (Trial) | Coefficient | Standard Error | P[|Z|>z] |
|---|---|---|---|
| Sales and Training | 0.0377 | 0.0229 | 0.0986 |
| Government Program | 0.1059 | 0.0589 | 0.0722 |
| Net Worth | -0.0337 | 0.0127 | 0.0079 |
| Leverage | -0.0534 | 0.0237 | 0.0239 |
| Government/Sales* | -0.0095 | 0.0094 | 0.3124 |
| Total Acres | 0.0000 | 0.0000 | 0.0866 |
| Years Farmed | 0.0035 | 0.0016 | 0.0281 |
| Farmer Education | -0.0431 | 0.0169 | 0.0106 |
| Soil Type | -0.0116 | 0.0062 | 0.0591 |
| Crop Rotation | -0.0038 | 0.0105 | 0.7175 |
| Land Location | 0.0018 | 0.0009 | 0.0415 |

| Marginal Effects, Y=1 (Uniform) | Coefficient | Standard Error | P[|Z|>z] |
|---|---|---|---|
| Sales and Training | -0.0959 | 0.1255 | 0.4448 |
| Government Program | 0.2310 | 0.0935 | 0.0134 |
| Net Worth | -0.1665 | 0.0537 | 0.0019 |
| Leverage | 0.0232 | 0.0360 | 0.5193 |
| Government/Sales* | -0.0161 | 0.0708 | 0.8196 |
| Total Acres | 0.0001 | 0.0000 | 0.0072 |
| Years Farmed | 0.0038 | 0.0047 | 0.4218 |
| Farmer Education | 0.0705 | 0.0362 | 0.0516 |
| Soil Type | 0.0148 | 0.0100 | 0.1409 |
| Crop Rotation | -0.0438 | 0.0257 | 0.0882 |
| Land Location | 0.0107 | 0.0030 | 0.0004 |

| Marginal Effects, Y=2 (Grid) | Coefficient | Standard Error | P[|Z|>z] |
|---|---|---|---|
| Sales and Training | -0.0620 | 0.0249 | 0.0126 |
| Government Program | 0.0008 | 0.0340 | 0.9810 |
| Net Worth | 0.0054 | 0.0213 | 0.7984 |
| Leverage | 0.0415 | 0.0126 | 0.0010 |
| Government/Sales* | 0.0360 | 0.0144 | 0.0123 |
| Total Acres | -0.0001 | 0.0000 | 0.0008 |
| Years Farmed | -0.0017 | 0.0026 | 0.5197 |
| Farmer Education | -0.0079 | 0.0198 | 0.6888 |
| Soil Type | 0.0049 | 0.0031 | 0.1108 |
| Crop Rotation | 0.0173 | 0.0088 | 0.0492 |
| Land Location | -0.0004 | 0.0011 | 0.7213 |
### Table 6. Continued

| Variable                     | Coefficient | Standard Error | P[|Z|>|z|] |
|------------------------------|-------------|----------------|---------|
| Sales and Training           | 0.1202      | 0.1079         | 0.2652  |
| Government Program           | -0.3378     | 0.1045         | 0.0012  |
| Net Worth                    | 0.1947      | 0.0556         | 0.0005  |
| Leverage                     | -0.0113     | 0.0378         | 0.7659  |
| Government/Sales*            | -0.0104     | 0.0587         | 0.8596  |
| Total Acres                  | 0.0000      | 0.0000         | 0.9271  |
| Years Farmed                 | -0.0057     | 0.0056         | 0.3084  |
| Farmer Education             | -0.0194     | 0.0416         | 0.6408  |
| Soil Type                    | -0.0081     | 0.0099         | 0.4131  |
| Crop Rotation                | 0.0303      | 0.0255         | 0.2362  |
| Land Location                | -0.0121     | 0.0036         | 0.0007  |

Government/Sales* is the combined-effect of Government Programs and Sales and Training.

Probabilities at the Mean Vector: 0 = 0.047, 1 = 0.458, 2 = 0.090, 3 = 0.405.
Table 7. Multinomial Logit for Precision Agriculture Adoption Model without Combined-Effect Variable.

<table>
<thead>
<tr>
<th>Independent Variable</th>
<th>Uniform</th>
<th>Grid</th>
<th>Management Zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sales Visit</td>
<td>-0.584</td>
<td>-0.267</td>
<td>-0.163</td>
</tr>
<tr>
<td>s.e.</td>
<td>0.003</td>
<td>0.094</td>
<td>0.091</td>
</tr>
<tr>
<td>Total Acres</td>
<td>5.194E-04</td>
<td>-1.250E-03</td>
<td>4.207E-04</td>
</tr>
<tr>
<td>s.e.</td>
<td>0.320</td>
<td>0.162</td>
<td>0.407</td>
</tr>
<tr>
<td>Acres Owned</td>
<td>-1.305E-03</td>
<td>1.679E-03</td>
<td>8.485E-05</td>
</tr>
<tr>
<td>s.e.</td>
<td>0.891</td>
<td>0.174</td>
<td>0.929</td>
</tr>
<tr>
<td>Enrolled in EQIP</td>
<td>-0.217</td>
<td>-0.409</td>
<td>-0.563</td>
</tr>
<tr>
<td>s.e.</td>
<td>0.696</td>
<td>0.517</td>
<td>0.318</td>
</tr>
<tr>
<td>Leverage</td>
<td>0.742</td>
<td>1.137</td>
<td>0.431</td>
</tr>
<tr>
<td>s.e.</td>
<td>0.257</td>
<td>0.092</td>
<td>0.524</td>
</tr>
<tr>
<td>Soil Type</td>
<td>0.257</td>
<td>0.261</td>
<td>0.203</td>
</tr>
<tr>
<td>s.e.</td>
<td>0.043</td>
<td>0.057</td>
<td>0.095</td>
</tr>
</tbody>
</table>

Goodness of Fit Measures
- McFadden’s $R^2$: 0.333
- Cox and Snell $R^2$: 0.603
- Nagelkerke $R^2$: 0.643
- $\chi^2$ Test: 122.068
- d. of f.: 18
APPENDIX C. GEOGRAPHICAL REPRESENTATION

The counties represented by at least one farmer in this survey are highlighted in green.