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I am submitting herewith a thesis written by Jonathan Core Walton entitled “Technology Adoption and Abandonment in Precision Cotton Production.” I have examined the final paper copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Agricultural Economics.

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TECHNOLOGY ADOPTION AND ABANDONMENT
IN PRECISION COTTON PRODUCTION

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Jonathan Core Walton
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Abstract

The data intensive nature of precision farming necessitates the use of different technologies to collect, transmit, manipulate, and apply information. Understanding the economic factors associated with decisions regarding technology adoption and abandonment is essential to the continued growth and feasibility of precision farming. The development of precision agricultural technologies, as well as educational and promotional efforts concerning precision farming, can benefit from an understanding of the factors influencing adoption and abandonment of precision agricultural technology. The first part of the study examined farm and farmer characteristics influencing the adoption and subsequent abandonment of precision soil sampling in cotton production. The second part of the study analyzed farm and farmer characteristics influencing adoption of personal digital assistants (PDA) and other handheld computers with global positioning systems (GPS) capabilities in cotton production.

Farm and farmer characteristics affecting adoption and abandonment of precision soil sampling in cotton production were examined first using univariate analysis of farm and farm characteristics of adopters and non-adopters and second using probit analysis. Younger, more educated farmers who had positive perceptions about the future of precision agriculture, and who operated larger farms were more likely to adopt precision soil sampling. Computer use in farm management and placing a greater percentage of cropped acres in crops other than cotton also positively influenced adoption. Younger farmers who used variable-rate application of inputs were less likely to abandon precision soil sampling. Acreage and the percentage of cropped acres in crops other than cotton positively influenced abandonment.

Results indicate that younger farmers who perceive that Extension services were useful in making precision farming decisions have a higher probability of adopting a PDA or handheld GPS device. The presence of greater yield variability and the use of remotely sensed crop images, grid soil sampling, plant mapping, and variable-rate application of certain inputs also increase the probability of adoption. Percentages of PDA/handheld GPS device use were highest for variable-rate application of fertilizer and lime, management zone identification, drainage management, and the application of growth regulator.

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Part 1: Introduction

A farmer's ability to gain access to information, interpret data, and apply that knowledge in a meaningful way is an important component of a successful management portfolio that maintains a competitive position in the agricultural marketplace. Advances in the development and practicality of computer-based information technologies affect input management decisions in agriculture. Increasing the level of information available to a decision maker decreases the level of uncertainty involved in making decisions (Babcock et al. 1996). One decision facing farmers is whether to adopt an information technology. A second decision facing producers who have already adopted an information technology is whether to continue its use.

Economic utility theory uses as its foundation the different choices individuals make based on their characteristics and circumstances. Extensive research has been conducted into the factors that drive the decision to adopt agricultural technology (e.g., Griliches 1957; Feder and Slade 1984; Khanna 2001; Daberkow and McBride 2003; Roberts et al. 2004). These studies examined the role that farm and farmer characteristics play in the adoption of new technologies and the diffusion of those technologies throughout commodity-specific portions of the agricultural market. As new technologies are developed, factors affecting adoption evolve in response to the demands placed on producers. Research is needed to understand and keep pace with the evolution of agricultural technologies including precision farming technology.

Previous research into the adoption of technology in agriculture has focused on farm and farmer characteristics and the role they play in decision making. Griliches (1957) and Feder and Slade (1984) provide an approach to modeling economic decision making in the context of technology in agriculture. Information technology has the

unique function in agriculture of not usually changing the production process but improving the control of other technologies and thus improving the efficiency of the process (Batte and Johnson 1993). The introduction of personal computers and the creation of more efficient computer-based technology have accelerated growth and advancements in the field of precision agriculture. Putler and Zilberman (1988), Batte, Jones, and Schnitkey (1990), Amponsah (1995), and Hoag, Ascough, and Frasier (1999) all looked at factors contributing to the adoption of computers for use in information management in agriculture. They used econometric techniques to examine the role that farm and farmer characteristics played in the adoption of computers. Farmer characteristics such as age and formal education were examined along with farm characteristics such as farm size, land tenure, type of crop operation, enterprise diversification, and farm income. Daberkow and McBride (2003) concluded that awareness of precision technologies did not significantly affect adoption. They found that farmers for whom precision technologies would be profitable were part of group with similar characteristics and due to these characteristics were more likely to be actively seeking information and better able to measure the risk of an innovation as well as its benefits.

Khanna (2001) and Roberts et al. (2004) looked at the adoption of site-specific information technologies and the role they played in determining the adoption of variable-rate application of inputs. Khanna (2001) found that farm size and measures of human capital did not significantly affect the adoption of soil testing. These variables did however significantly affect the adoption of variable-rate technology. Their results also indicate that ownership of land was inversely related to the adoption of variable rate

technology. Alternatively, Roberts et al. (2004) found that farm size and measures of human capital were significantly related to the adoption of information technology in general and grid and zone soil testing in particular. Ownership of land did not have a significant effect on the adoption of soil testing or variable rate technology. Both of these studies found that measures of soil quality significantly affected the adoption of variable rate technology.

Past research exists which analyzes adoption decisions in agriculture; however, little work has analyzed the decision to abandon agricultural technologies or continue their use. Barham et al. (2004) and Carletto, de Janvry, and Sadoulet (1996) looked at adoption and subsequent abandonment of hormone use in dairy cattle and export crops respectively. Their research provides a starting point in developing a foundation for analysis of abandonment of precision agricultural technologies. Research has determined factors related to the abandonment of assistive technology used by individuals with physical disabilities (Phillips and Zhao 1993; Reimer-Reiss and Wacker 2000). Ewusi-Mensah and Przasnyski (1994) examined factors contributing to abandonment of technology in information-systems development projects. Important parallels can be drawn from this research to evaluate the abandonment of precision agricultural technology.

Carletto, de Janvry, and Saudoulet (1996) looked at the determinants of adoption and subsequent abandonment of non-traditional export crops in Guatemala. Adoption and abandonment decisions were modeled based on utility as a function of variables including land ownership, land quality, human capital, social capital (cooperative membership in this case), geographical location, year of adoption in relation to specific market events,

age of household, and the number of years adoption had been a possibility. Their results indicated that the size and quality of land holdings did not affect adoption but did affect abandonment. Farmers with more land and higher quality land were less likely to abandon. The availability of irrigation was a significant factor affecting adoption and the ability to continue production. Human capital measures were important to adoption but were overwhelmed by significant production and marketing shocks that influenced abandonment. The capital intensive nature of non-traditional export crops influenced adoption decisions through membership in cooperatives as they were the primary source of capital. The strength of these institutions over time therefore significantly affected abandonment.

Differences in characteristics between adopters who continue to use a technology and those who discontinue its use after a period of time need to be examined to understand the phenomena of abandonment. Foltz and Chang (2002) found that the characteristics of Connecticut dairy farmers who adopted recombinant bovine somatotropin (rBST) were similar to farmers that adopted this technology and later abandoned. The primary differences in characteristics came in the areas of computer adoption and profit per cow. Those who abandoned rBST were significantly less likely to use a computer and had higher profits per cow. Barham, et al. (2004) arrive at similar conclusions from a study of rBST adoption and abandonment in Wisconsin.

Studies conducted outside of agriculture could provide insight into abandonment decisions. In their study of the abandonment of assistive technology for individuals with a physical disability, Phillips and Zhao (1993) found that consideration of users' opinions, device procurement, device performance, and changes in users needs were significantly

related to device abandonment. Reimer-Reiss and Wacker (2000) underscore the significance of the role consideration of the end-users' opinion plays in assistive device abandonment. Ewusi-Mensah and Przasnyski (1994) found in their study of information systems technology abandonment in Fortune 500 companies that decisions to end or abandon an information systems development project were the result of issues that could be grouped into economic, organizational, and technological concerns. The primary factors contributing to information systems project abandonment were escalating project costs, lengthening completion schedules, and lack of technical infrastructure and expertise.

As the horizons of precision farming broaden the speed and efficiency with which precision farming data are collected, analyzed, and used is becoming an ever greater concern. The adoption of technology such as Global Positioning System (GPS) enabled personal digital assistants (PDA) and other handheld GPS devices is a product of the need for more efficient handling of data in precision farming. The use of PDAs and other handheld computing devices allows the movement of precision farming data such as yield maps, management zone maps, and remotely sensed images from the farm or crop consultant office to the field. More efficient data movement and storage has the potential to increase the efficiency of scouting and ground truthing. Increases in information management efficiency can then lead to greater efficiencies in input application. Currently little research has been conducted to examine the movement of data through PDAs and other handheld computing devices in precision farming.

Understanding the farm and farmer characteristics associated with the adoption of information technologies, such as precision soil sampling or PDA/handheld GPS

devices, is useful in helping agribusiness firms tailor products to more closely match the demands of farmers. University Extension personnel could also use information about farmers' decisions to tailor support and curricula to address education issues involving these types of information technologies. The characteristics of those who choose to abandon a technology could be particularly important to agribusiness firms in the refinement of current products and in future product development.

Factors constraining the technical feasibility of precision agricultural practices contribute to the adoption of technology to ease these barriers. McKinnon et al. (2004) examined the possibility of using a wireless local area network to transmit precision farming data. Limits on existing communication infrastructure make the transmission of some types of time sensitive data inefficient if not impossible. This study looked at the transmission of multispectral images used in variable rate application of inputs in cotton production. After transmission through the wireless local area network, images were carried to the field using personal digital assistants for the purpose of ground-truthing.

Outside of agriculture handheld computers have also been linked to a global positioning system to assistance in the management of spatially coordinated data. Dwolatzky et al. (2006) used a PDA with GPS capabilities to locate tuberculosis patients in South Africa who were delinquent in receiving treatments. The use of this technology reduced time to locate patients compared with the use of aerial photographs in areas where street maps were unobtainable or unreliable.

The objective of the first portion of this research was to determine the farm and farmer characteristics that affect the adoption and subsequent abandonment of grid and zone soil sampling. The objective of the second portion was to determine the farm and

farmer characteristics that influence the adoption of PDA/handheld GPS devices and to examine their different uses in precision agriculture. An important distinction between these two objectives is the examination of the uses of PDA/handheld GPS devices in making precision farming decisions as well as an examination of the role complementary technologies play in PDA/handheld GPS adoption. Precision soil sampling, whether by grid or management zone, produces spatially referenced data capable of standing alone as a representation of the variability of soil fertility and chemistry. PDA/handheld GPS devices, on the other hand, are used in cooperation with other technologies in the collection, management, and application of spatially referenced soil and crop data in precision farming.

The separate portions of this research presented as independent examinations of economic phenomena affecting precision agriculture are linked by the fact that a limited body of research exists exploring particular specialized aspects of each technology. Precision soil sampling has in common many basic aspects of technologies whose adoption has been thoroughly studied, but abandonment of technology of any type has received significantly less attention. The use of PDA/handheld GPS devices in precision agriculture is important as an indicator of the evolution of precision agriculture as the collection, interpretation, and management of data grows in intensity. Research examining this evolution through the study of economic behavior such as technology adoption is also limited.

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Part 2: Adoption and Abandonment of Precision Soil Sampling in Cotton Production

Introduction

The decision to adopt a technology is based on the expected economic benefits gained through the use of that technology. Extensive research has determined what influences the perceptions of decision makers in situations involving the adoption of technology. The current literature contains many examples of research explaining farm and farmer characteristics associated with the adoption of agronomic decision-making technologies (e.g., Feder and Slade 1984; Putler and Zilberman 1988; Batte, Jones, and Schnitkey 1990; Amponsah 1995; Daberkow and McBride 2003). But analysis of the reasons why producers abandon such technologies has received significantly less attention. If the producer perceives the benefits produced by the technology to be less than the costs associated with adoption, the technology may be abandoned. Rogers (1983) refers to this type of abandonment decision as “disenchantment discontinuance.” Like other agricultural technologies, it is possible that some precision agricultural technologies are abandoned in favor of newer, more efficient technologies. Rogers (1983) categorizes these decisions as “replacement discontinuance.”

Precision farming technologies include information technologies and variable-rate application technologies. As new technologies are developed, factors affecting adoption and abandonment change. Research is needed to understand and keep pace with this evolution. Previous research (e.g., Khanna 2001; Roberts et al. 2004) has examined the relationship between site-specific information gathered using soil testing technology and the adoption of variable-rate application of inputs in agriculture. The relationship between the information gathered and other precision farming activities, such as variable rate application, makes information technology a logical starting point for examining the

adoption-abandonment phenomenon. Barham et al. (2004) and Carletto, de Janvry, and Sadoulet (1996) looked at adoption and subsequent abandonment of hormone use in dairy cattle and export crops respectively. Their research provides a starting point in developing a foundation for analyzing abandonment of precision agricultural technologies. Foltz and Chang (2002) and Barham et al. (2004) conducted research on the adoption of recombinant bovine somatotropin (rBST), and examined the characteristics of farmers who abandoned the use of that technology. Barham et al. (2004) found that abandonment decisions could be dampened in cases where adoption of technology involves a significant sunk cost. Grid and management zone soil sampling only have variable costs associated with the amount of acreage and the sampling rate (Swinton and Jones 1998). An important parallel between rBST and soil sampling technologies is that they both have low sunk costs associated with adoption. The results of the rBST adoption studies did not find any differences between the characteristics adopters and those who abandoned.

This research focuses on the adoption and subsequent abandonment of precision soil sampling by cotton producers in 11 Southeastern states (Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, Missouri, North Carolina, South Carolina, Tennessee, and Virginia). Current levels of site-specific soil sampling are high enough to create a usable pool of data from which abandonment can be examined. Whipker and Akridge (2006) found that 45% of dealerships providing precision agricultural services offered soil sampling that was geographically referenced by grid, soil type, or management zone. Roberts et al. (2005) found that 41% of cotton producers used precision soil sampling on

at least some of their cotton acreage in 2003 and 2004. Additional research is needed to explain abandonment as it applies to U.S. crop agriculture and precision farming.

The objective of this research was to determine the farm and farmer characteristics that affect the adoption and subsequent abandonment of grid and management zone soil sampling in precision cotton production. Precision agricultural technologies are typically more profitable with high valued crops, such as cotton (Swinton and Lowenberg-Deboer 1998). Knowledge of the characteristics associated with abandonment can provide greater insight into the adoption process as well as assist with the development and evolution of technologies to better suit the needs of end-users.

Data

Data for this research came from Roberts et al. (2005). The data was gathered from a survey of cotton producers in Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, Missouri, North Carolina, South Carolina, Tennessee, and Virginia. The survey questionnaires were mailed on January 28, 2005. Reminders and follow-up mailings were sent on February 4, 2005 and February 23, 2005. Of 12,243 surveys mailed 200 were returned either undeliverable or by farmers indicating they were not cotton producers. A total of 12,043 cotton farmers were left in the population after these exclusions. 1,216 cotton producers responded to the questionnaire giving a response rate of 10%. Producers responded to the survey providing information about the extent to which precision agricultural technologies were used on their farms as well as information on the general structure and characteristics of their farming operations. Producers answered questions concerning their opinions on the costs and profitability of precision agriculture as well as their perceptions of the future viability of precision agriculture.

Producers answered questions concerning their opinions on the costs and profitability of precision agriculture as well as their perceptions of the future viability of precision agriculture. A total of 827 observations were available for analysis of precision soil sampling adoption after eliminating observations with missing data. The subset of the sample used to analyze abandonment of precision soil sampling came from those who indicated that they had adopted precision soil sampling. This subset included 335 adopters, 56 of whom had abandoned precision soil sampling. Selected comparisons of this data to the 2003 United States Department of Agriculture Agricultural Resource Management Survey (ARMS) were used to determine the degree to which the data used represented cotton farmers nationwide.

Methods and Procedures

Analytical Framework

Assuming that the farmer makes decisions to maximize expected utility through profit, let U_A represent the expected utility from adopting precision soil sampling and U_{NA} represent the expected utility from not adopting precision soil sampling. Letting $U_A^* = U_A - U_{NA}$, the farmer is expected to

- (1) Adopt precision soil sampling when $U_A^* > 0$, and
- (2) Not adopt precision soil sampling when $U_A^* < 0$.

Farmers who choose to adopt precision soil sampling are self-selected into a group faced with the choice of continuing to use or abandon it. In this case, let

$U_C^* = U_C - U_{NC}$, where U_C represents the expected utility from continuing to use

precision soil sampling and U_{NC} represents the expected utility from not continuing its use or abandoning it. To maximize utility in this case, the farmer is expected to

- (3) Continue the use of soil sampling when $U_C^* > 0$ given that $U_A^* > 0$ and
- (4) Discontinue, or abandon, the use of soil sampling when $U_C^* < 0$ given that $U_A^* > 0$.

The sequence of these decisions can be seen in Figure 1 (Figures and Tables appear in the appendices).

The unobservable decision variables U_A^* and U_C^* are hypothesized to be functions of exogenous variables (Z_A and Z_C) and parameters (γ_A and γ_C) with random errors (e_A and e_C),

$$(5) U_A^* = Z_A \gamma_A + e_A, \text{ and}$$

$$(6) U_C^* = Z_C \gamma_C + e_C.$$

While U_A^* and U_C^* are not directly observable, the farmer's observable decisions are represented by the following binary variables (Khanna 2001):

$$(7) I_A = 1 (\text{if } U_A^* > 0) \text{ and } 0 \text{ otherwise, and}$$

$$(8) I_C = 1 (\text{if } U_C^* > 0 | I_A = 1) \text{ and } 0 \text{ otherwise.}$$

Multiplication of the unobserved variables U_A^* or U_C^* by any positive constant does not change the interpretation of I_A or I_C . Thus, it is common to assume that the variance of the error term $Var(e_i) = 1$ following the assumptions associated with standard normal distributions, $\mu = 0$ and $\sigma^2 = 1$. Under this assumption the relationships between equations (5) and (7) yield

$$\begin{aligned}
P_A &= \Pr(I_A = 1) \\
&= \Pr(U_A^* > 0) \\
(9) \quad &= \Pr[e_A > -(Z_A \gamma_A)] \\
&= 1 - \Phi_A[-(Z_A \gamma_A)]
\end{aligned}$$

where P_A is the probability of adoption, $\Pr(I_A = 1)$ is the probability of positive response to the adoption question, and Φ_A is the cumulative distribution function for e_A . The symmetric qualities of the standard normal distribution can be used to show that

$$(10) \quad 1 - \Phi_A[-(Z_A \gamma_A)] = \Phi_A(Z_A \gamma_A).$$

Relating equation (9) to equation (10) shows the probability of adoption as:

$$(11) \quad P_A = \Phi_A(Z_A \gamma_A).$$

Given the probabilities stated in equations (9) and (11), the sample likelihood function can be written as:

$$(12) \quad L = \prod_{I_A=1} \Phi_A(Z_A \gamma_A) \prod_{I_A=0} \Phi_A(-Z_A \gamma_A).$$

Continuing the assumption that errors are distributed normally, equations (6) and (8) yield the following probabilities for continuing the use of information technologies:

$$\begin{aligned}
P_C &= \Pr(I_C = 1 \mid I_A = 1) \\
&= \Pr(U_C^* > 0 \mid U_A^* > 0) \\
(13) \quad &= \Pr[e_C > -(Z_C \gamma_C) \mid e_A > -(Z_A \gamma_A)] \\
&= [1 - \Phi_C[-(Z_C \gamma_C)] \mid 1 - \Phi_A[-(Z_A \gamma_A)]]
\end{aligned}$$

where Φ_C is the cumulative distribution function for e_C . As in equation (10), the symmetric qualities of the standard normal distribution can again be used to show that:

$$(14) \quad 1 - \Phi_C[-(Z_C \gamma_C)] = \Phi_C(Z_C \gamma_C).$$

Linking equations (13) and (14) gives the conditional probability of continuing the use of precision soil sampling as:

$$(15) P_C = \Phi_C(Z_C \gamma_C) | \Phi_A(Z_A \gamma_A).$$

Given the probabilities stated in equations (9) and (11), the sample likelihood function for continuance can be written as:

$$(16) L = \prod_{I_C=1|I_A=1} \Phi_C(Z_C \gamma_C, \rho) \prod_{I_C=0|I_A=1} \Phi_C(-Z_C \gamma_C, -\rho),$$

where ρ is the correlation between e_C and e_A .

The conditionality of equation (15) exists because an abandonment decision only occurs if the producer adopted the technology. If $\rho \neq 0$, estimation of the parameters of the two equations is accomplished using a bivariate probit model with sample selection. Through the use of this sample selection procedure, only those responses with $I_A = 1$ will be used in estimating the model associated with the I_C decision. Heckman (1976) developed the two-step selection procedure to account for selection bias where a censored dependent variable, abandonment in this case, occurs. Selection bias is measured in terms of the level of correlation between the errors terms of both equations. If $\rho = 0$ no significant evidence of selection bias exists, and equations (5) and (6) can be estimated separately from their respective populations with individual probit models.

Comparison of Sample Means

Comparisons of characteristics between the different population subsets were made to provide further insight into the factors motivating adoption and abandonment. Adopters of precision soil sampling were compared with those who did not adopt, and those who abandoned precision soil sampling were compared with those who continued

its use. An F test was used to determine if the variances of the characteristic variables from each subset were significantly different. The means for each of the observed farm and farmer characteristic variables were compared using an appropriate t test assuming equal or unequal variances depending on the results of the F test.

Empirical Models

Models for precision soil sampling adoption and abandonment as a function of farm and farmer characteristics were specified as follows:

(20)

$$\begin{aligned} ADOPT_i = & \beta_0 + \beta_1 LIVEST_i + \beta_2 PROFIT_i + \beta_3 ACRES_i + \beta_4 OCROPS_i + \beta_5 LANDTEN_i \\ & + \beta_6 YVAR_i + \beta_7 AGE_i + \beta_8 QUADAGE_i + \beta_9 EDUC_i + \beta_{10} COM_i + \beta_{11} INCOME_i \\ & + \beta_{12} EXTEN_i + \beta_{13} ERS1_i + \beta_{14} ERS5_i + \beta_{15} ERS7_i + \beta_{16} ERS9_i + e_i, \end{aligned}$$

(21)

$$\begin{aligned} ABANDON_j = & \alpha_0 + \alpha_1 LIVEST_j + \alpha_2 PROFIT_j + \alpha_3 ACRES_j + \alpha_4 OCROPS_j + \alpha_5 LANDTEN_j \\ & + \alpha_6 YVAR_j + \alpha_7 AGE_j + \alpha_8 QUADAGE_j + \alpha_9 EDUC_j + \alpha_{10} COM_j + \alpha_{11} INCOME_j \\ & + \alpha_{12} EXTEN_j + \alpha_{13} YRSADOPT_j + \alpha_{14} VRPKL_j + \alpha_{15} RS1_j + \alpha_{16} ERS5_j + \alpha_{17} ERS7_j \\ & + \alpha_{18} ERS9_j + e_j, \end{aligned}$$

where $ADOPT$ equals one if the farmer adopted grid or zone soil sampling and zero otherwise, and $ABANDON$ equals one if the farmer abandoned grid or zone soil sampling and zero otherwise. Definitions of independent variables along with means and hypothesized signs are included in Tables 1 and 2.

Hypotheses

Six farmer characteristics were hypothesized to affect the adoption and abandonment decisions of cotton farmers (Table 1). Farmer age (AGE) was expected to be negatively associated with adoption of precision soil sampling and positively

associated with abandonment. As age increases the planning horizon decreases and limits the period of time in which farmers perceive they can make changes and offset learning costs (Batte, Jones, and Schnitkey 1990; Roberts et al. 2004). The quadratic age coefficient (QUADAGE) captures elements of experience. Adoption is expected to increase with age for younger farmers as experience with precision agricultural technologies is gained and decline after a certain age as the planning horizon shortens (Putler and Zilberman 1988; Alexander and Van Mellor 2005). The number of years of formal education (EDUC) was expected to positively influence adoption and negatively influence abandonment. Higher levels of formal education may facilitate the analytical ability of farm decision makers dealing with the volume and intricacy of data associated with precision agriculture (Batte, Jones, and Schnitkey 1990). In much the same way, the use a computer in farm management (COM) is expected to positively influence adoption and negatively influence abandonment. Because computer technology is either integrated into precision agricultural technology or it is necessary to convey and manipulate precision farming data, computer use for farm management is likely tied to adoption and abandonment decisions. Higher income levels (INCOME) are expected to be positively related to adoption and negatively related to abandonment. Higher income could facilitate investment in precision farming technologies while lack of resources may increase the level of abandonment due to an inability to obtain other complementary technologies (Rogers 1983). Farmers who felt that Extension services were useful in making precision farming decisions (EXTEN) were expected to be more likely to adopt precision soil sampling. These same perceptions are expected to negatively influence abandonment. The efforts of Extension to provide useful information to farmers could reduce factors

driving disenchantment discontinuance. Positive perceptions about the future profitability of precision agriculture (PROFIT) are expected to be positively related to adoption and negatively related to abandonment. Farmers could be more willing to adopt and keep using precision soil-sampling if they perceive future payoffs to be greater than costs.

Seven farm characteristics were hypothesized to affect adoption and/or abandonment of precision soil sampling (see table 1). The number of cotton acres planted (ACRES) represents a measure of enterprise size and is hypothesized to be positively related to adoption and negatively related to abandonment. Farmers who have larger cotton acreages are expected to be more likely to employ practices such as precision soil sampling due to the presence of scale economies in production. The percentage of total cropped acres devoted to other crops (OCROPS) is expected to positively influence adoption and negatively influence abandonment. Farmers who place greater emphasis on grain and oilseed crops are expected to transfer the use of precision agricultural technologies from that acreage to cotton acreage. Enterprise diversification, represented by livestock ownership (LIVEST), is expected to negatively influence adoption and positively influence abandonment. Fernandez-Cornejo, Beach, and Huang (1994) found that livestock production had a significant negative impact on the adoption of integrated pest management. Management of an enterprise not directly related to precision soil sampling reduces the operator's ability to devote time to utilizing precision soil data. The percentage of total cropped acres that is owned (LANDTEN) is hypothesized to be positively related to adoption and negatively related to abandonment. Farmers are likely to apply more managerial attention to owned land than rented land because the management of owned land may be passed to subsequent generations (Roberts et al.

2004). Yield variability (YVAR) is hypothesized to be positively related to adoption and negatively related to abandonment. The presence of greater yield variability potentially increases the ability to manage inputs more effectively. Technologies that increase management efficiency and input application efficiency can enhance profitability (Larson and Roberts 2004). The number of years precision soil sampling has been used (YRAADOPT) is hypothesized to be negatively related to abandonment. Continued use of a technology in subsequent years beyond the initial adoption period could be evidence that the technology has provided benefits to the adopter greater than the costs of adoption. Variable-rate application of phosphorus, potassium, and lime is hypothesized to be negatively related to abandonment. Similar to the number of years a technology has been adopted, the use of variable-rate application of inputs (VRPKL) could provide evidence that benefits from the adoption of precision soil sampling have outweighed associated costs and allowed the farmer to make decisions perceived as beneficial based on soil data.

Location variables in the form of USDA Economic Research Service farm resource regions (See table 2) were included in both the adoption and abandonment models to test if cotton producers in the Heartland (ERS1), Eastern Uplands (ERS5), Fruitful Rim (ERS7), and Mississippi Portal (ERS9) regions had higher or lower probabilities of adopting and abandoning precision soil sampling than cotton producers in the Southern Seaboard (ERS6) region (U. S. Department of Agriculture-Farm Resource Regions 2007). The Southern Seaboard region was chosen as the reference region because it had the modal number of survey responses. Percentage distribution of observations by state and farm resource region is contained in Table 7.

Exogeneity Tests

The inclusion of farmer choice variables in the estimation of the adoption and abandonment equations could create endogeneity issues. Complementary relationships between technologies and practices can affect farmer perceptions of the expected value of a decision (Barham et al. 2004). Variables in the adoption equation that were hypothesized to be potentially endogenous include cotton acreage (ACRES), percentage of total cropped acreage devoted to other crops (OCROPS), yield variability (YVAR), computer use in farm management (COM), and household income above \$150,000 (INCOME). Variables in the abandonment equation that were hypothesized to be potentially endogenous include cotton acreage (ACRES), percentage of total cropped acreage devoted to cotton (PERCOT), yield variability (YVAR), the number of years precision soil sampling has been used (YRAADOPT), computer use in farm management (COM), household income above \$150,000 (INCOME), and the use of variable-rate application of phosphorus, potassium, and lime (VRPKL). These variables were hypothesized to be potentially endogenous because variation in these variables could result from the adoption and abandonment decisions. The use of precision soil sampling could enable more efficient management of larger operations and help lower yield variability. Managing data obtained from precision soil sampling is most likely accomplished using computer based technology. Uncertainty regarding the issue of whether computers were used previously in management or if their use was a result of precision soil sampling adoption is a potential source for endogeneity. The use of precision soil sampling data has the potential to increase management efficiency increasing profit and thus increasing income reported by the producer. A decision to

continue the use of precision soil sampling has a direct effect on the number of years it is used. The use of variable-rate application requires data obtained from technologies such as precision soil sampling.

Testing for exogeneity of these variables was accomplished using a procedure outlined by Rivers and Vuong (1988). In this procedure, each potentially endogenous variable is regressed against all other exogenous variables and a vector of instrumental variables. The residuals from each of these equations are then included as additional explanatory variables in a separate estimation of the adoption and abandonment equations. Generalized residuals were calculated for potentially endogenous binary variables (Vella 1992). The residuals were tested for joint significance using a Wald test in both the adoption and abandonment equations (Wooldridge 2002). Failure to reject the null hypothesis of joint significance provides evidence that the variables are exogenous.

Multicollinearity Tests

The presence of collinear relationships among explanatory variables can influence the significance and inferential power of coefficients. Variance inflation factors were used to detect the presence of these collinear relationships. Variance inflation factors were calculated using the squared multiple correlation coefficient from the regression of each explanatory variable on all other explanatory variables. As the degree of variation in each individual explanatory variable explained by all other explanatory variables increases, the value of the variance inflation factor increases. Variance inflation factors with a value greater than 10 are often thought to indicate the presence of collinearity in the data (Chatterjee and Price, 1991).

Model Estimation

Equations (20) and (21) were estimated using maximum likelihood. A Wald test was performed to test the null hypothesis that the coefficient of $\rho = 0$. Overall significance of the model chosen was tested using a likelihood ratio test.

Results

Evaluation of Data

Comparison of these data to data from the 2003 United States Department of Agriculture Agricultural Resource Management Survey (ARMS) is a necessary caveat when considering the degree to which the results of this research represent cotton producers in the United States. Results of the 2003 ARMS show that 25% of cotton producers attended at least some college while the results of the survey data used in this research indicate that 53% of cotton producers attended at least some college. The ARMS survey reports an average of 501 acres of cotton per farm. The data from Roberts et al. (2005) used here reports an average of 818 acres of cotton per farm. Percentage of total income from farming averaged 45% in the ARMS data while the data used here show an average of 73% of total household income coming from farming (U.S. Department of Agriculture- ARMS 2007). Differences between the sample used here and the ARMS sample suggest that inferences to the general population of cotton farmers in the 11 states may not be appropriate and that farmers with certain characteristics may be underrepresented, but useful information can be obtained about the factors that influence adoption and abandonment for this sample.

Comparison of Sample Means

Results of the comparison between adopters and non-adopters can be found in Table 3. Analysis of these results indicates that producers who adopted precision soil sampling were younger, more educated, had higher income, and had a higher incidence of computer use in farm management. Producer perceptions about the future profitability of precision farming and the usefulness of Extension were greater for adopters than non-adopters. Adopters also, on average, farmed larger cotton acreages but devoted a smaller percentage of total cropped acres to cotton production.

Results from the comparison between the population subset of producers who abandoned precision soil sampling and those who continued its use are found in Table 4. Analysis of differences in means for the population subsets indicates that producers who abandoned precision soil sampling were less educated than those who continued its use. Results of this comparison also indicates that abandoners reported higher income levels, farmed larger cotton acreages, but devoted smaller percentages of total cropped acreage to cotton production.

Model Evaluation

With the exception of AGE and QUADAGE, variance inflation factors were under 2. Evidence indicating collinearity between AGE and QUADAGE is logical and to be expected given the nature of the variables. Nonetheless, the high variance inflation factors suggest that failure to reject the null hypothesis of zero parameter values for AGE and QUADAGE should be viewed with caution.

The Wald test indicated failure to reject the null hypothesis that $\rho = 0$ (Wald=2.66, $\chi^2 = 3.84$, d.f.=1, $\alpha=.05$) in the estimation of the adoption and

abandonment equations using a bivariate probit with sample selection. Thus, the individual binomial probit models for the adoption and abandonment equations are appropriate. χ^2 statistics indicate that both probit models were significant at the 5% level (Table 6). The ADOPT model correctly predicted 539 (65%) responses and the ABANDON model correctly predicted 285 (85%) responses. Tests failed to reject the hypothesis of statistical exogeneity of the hypothesized variables at the 5% level (Table 5). While these tests demonstrate that endogenous variables do not statistically harm the results of the estimations, the potential for economic endogeneity is noted in the relationships of these variables to the choice variables being analyzed.

Precision Soil Sampling Adoption

Results from the estimation of the adoption equation can be seen in Table 6. Cotton acreage (ACRES), perceptions about the future profitability of precision agriculture (PROFIT), the number of years of education (EDUC), and the use of a computer in farm management (COM) positively affected the probability that a farmer chooses to adopt precision soil sampling. These significant variables had signs that agreed with those hypothesized. The percentage of total cropped acreage devoted to cotton (OCROPS) significantly affected the adoption of precision soil sampling. Results from the estimation of the adoption equation indicate this variable is positively related to adoption. Enterprise diversification (LIVEST), land tenure (LANDTEN), yield variability (YVAR), farmer age (AGE), farmer age squared (QUADAGE), pre-tax household income (INCOME), and perceptions about the usefulness of extension (EXTEN) did not affect the probability that a farmer would choose to adopt precision soil sampling. The

probability of adoption in other ERS Farm Resource Regions was not significantly different from adoption in the Southern Seaboard region.

These results suggest that farmers who were more educated, farmed more acres of cotton, used computers in farm management, had positive perceptions of the future of precision agriculture, and had a larger proportion of their cropped acreage in crops other than cotton had a higher probability of adopting precision soil sampling. These findings are consistent with the existing body of literature on adoption, and in particular the findings of Roberts et al. (2004) concerning adoption of sight-specific information technology. A noticeable dissimilarity to existing literature on adoption, however, is the lack of significance of the age variable. Sensitivity analysis conducted by eliminating the quadratic age term from the adoption equation supports the hypothesis that age significantly affects adoption but high variance inflation factors for AGE and QUADAGE suggest that the standard errors of the estimates are biased upward by the presence of multicollinearity.

Precision Soil Sampling Abandonment

Cotton acreage (ACRES), percentage of total cropped acres devoted to other crops (OCROPS), farmer age (AGE), farmer age squared (QUADAGE), number of years precision soil sampling had been used (YRAADOPT), and variable-rate application of phosphorus, potassium, and lime (VRPKL) significantly affected the probability of abandoning precision soil sampling. These variables, with the exception of cotton acres (ACRES), had signs that confirmed earlier hypotheses. Cotton acres (ACRES) positively affected the probability of abandonment. An alternative to the hypothesis presented concerning this variable is that larger acreages require increased management attention

and therefore the profitability of an investment in precision agriculture is subject to a higher level of scrutiny. This higher level of scrutiny would increase the probability of abandonment if a lack of net benefits were perceived. Variables that did not significantly affect the probability of abandoning precision soil sampling include enterprise diversification (LIVEST), perceptions about the future profitability of precision agriculture (PROFIT), land tenure (LANDTEN), yield variability (YVAR), number of years of education (EDUC), pre-tax household income (INCOME), and perceptions about the usefulness of extension (EXTEN). Results showed that the probability of abandonment was significantly lower in the Eastern Uplands region than the Southern Seaboard region. Adopters in other ERS Farm Resource regions were not significantly different than farmers in the Southern Seaboard in their abandonment of precision soil sampling.

Results indicating that cotton acreage positively affected the probability of abandoning precision soil sampling supports the findings of Foltz and Chang (2002) and Barham et al. (2004). Their findings show that adopters and abandoners share many of the same characteristics. Analysis of the population subsets from the data shows that abandoners of precision soil sampling planted a higher average number of acres than the adopter subset. Those who adopted precision soil sampling planted an average of 1020 acres of cotton while those who abandoned precision soil sampling planted an average of 1390 acres. This lends credence to the earlier stated alternative hypothesis that larger acreages require increased management attention and therefore the performance of a technology is subject to a higher level of scrutiny. An increased level of attention paid to

the performance of precision soil sampling could foster abandonment decisions when poor performance is observed.

The positive coefficient associated with non-cotton acreage as a percentage of total cropped acres is consistent with the previous hypothesis for this variable. As the percentage of total acreage devoted to cotton increases, the probability of abandonment is diminished. This result indicates that crop enterprise diversification increases the probability of abandonment of precision soil sampling in cotton. It is possible that while some farmers may use diversification as a tool to manage risk others may use information obtained through the use of technology such as precision soil sampling to manage risk.

The positive coefficient for the age variable is consistent with accepted hypotheses concerning the effects of shortened planning horizons of decision making. The negative coefficient for the quadratic age term captures elements of the role experience plays in decision making. Younger, less experienced, farmers are more likely to abandon, but as age increases experience is gained which lowers the level of abandonment. Beyond a certain age, the effect of experience diminishes and the role of shortened planning horizons begins to take affect, increasing the likelihood of abandonment.

Negative coefficients for the number of years adopted and for the use of variable-rate application of inputs are consistent with earlier stated hypotheses. Continuing the use of precision soil sampling in subsequent years after the initial adoption year demonstrates perceived benefits were greater than associated costs. Using data obtained from an information gathering techniques such as precision soil sampling for the variable rate

application of inputs is also evidence the value obtained from adoption is greater than the associated costs.

Summary and Conclusion

Farmer decisions regarding the adoption and abandonment of precision soil sampling were analyzed as a function of observable farm and farmer characteristics. Because adoption is a prerequisite to abandonment, equations were estimated sequentially to provide a basis for comparison of the farmer and farmer characteristics affecting adoption and abandonment.

The results from probit regressions suggest that younger farmers with larger cotton acreages who had positive perceptions about the future profitability of precision agriculture and who used a computer in farm management were more likely to adopt precision soil sampling. Results showed that farmers who devoted larger percentages of their acreage to the production of other crops were more likely to adopt precision soil sampling for cotton production. Thus, evidence exists that farmers transferred technology familiarity and use from other crops to cotton. Of those who adopted, younger farmers in the Eastern Uplands region who used precision soil sampling technology a greater number of years and utilized variable-rate application of inputs were less likely to abandon. Results also showed that adopters with larger cotton acreages were more likely to abandon. This result suggests that farmers operating larger acreages of cotton applied greater scrutiny to management practices.

The marketing efforts of agribusiness firms could benefit from tailoring efforts towards younger farmers with larger cotton acreages as they attempt to promote precision soil sampling services. An important conclusion drawn from this research is that

agribusiness firms wishing to maintain the use of precision soil sampling technology could benefit from promoting other technologies and practices that make use of the site-specific data obtained from soil sampling. Extension personnel could also create educational programs that would emphasize the application of precision soil sampling data in production.

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Appendix

Table 1. Variable Definitions, Hypothesized Signs, and Means in the Precision Soil Sampling Adoption and Abandonment Equations

Variable	Definition	Hypothesized sign		Mean
		Adopt	Abandon	
Farmer Characteristics				
<i>AGE</i>	Age in years of the primary decision maker	–	+	49.98
<i>QUADAGE</i>	Age in years squared	+	–	2576.31
<i>EDUC</i>	Number of years of formal education	+	–	14.29
<i>COM</i>	Equals one if the farmer uses a computer for farm management and zero otherwise	+	–	0.58
<i>EXTEN</i>	Equals one if the farmer perceived extension services helpful in implementing precision farming practices	+	–	0.84
<i>PROFIT</i>	Equals one if the farmer thought that it would be profitable to use precision agricultural technologies in the future and zero otherwise	+	–	0.54
Farm Characteristics				
<i>ACRES</i>	Average cotton acreage grown in 2003 and 2004	+	–	800.34
<i>OCROPS</i>	Percentage of non-cotton acreage to total cropped acreage	+	–	23.54
<i>LIVEST</i>	Equals one if the farming operation includes livestock and zero otherwise	–	+	0.27
<i>LANDTEN</i>	Percentage of owned land to total land farmed	+	–	31.17

Table 1. Continued

Variable	Definition	Hypothesized sign		Mean
		Adopt	Abandon	
<i>YVAR</i>	Difference between the farmer's estimates of average yields for the most productive 1/3 of and the least productive 1/3 of a typical field	+	–	522.33
<i>INCOME</i>	Equals one if pre-tax household income is greater than \$150,000	+	–	0.33
<i>YRSADOPT</i>	Number of years precision soil sampling was used		+	4.12
<i>VRPKL</i>	Equals one if variable-rate application of P, K, or L was used and zero otherwise		–	0.2

Table 2. Location Variables in Precision Soil Sampling Adoption and Abandonment Equations

Variable	Definition	Hypothesized sign		Mean
		Adopt	Abandon	
Location Variables				
<i>ERS1</i>	Heartland	+ −	+ −	0.035
<i>ERS5</i>	Eastern Uplands	+ −	+ −	0.052
<i>ERS7</i>	Fruitful Rim	+ −	+ −	0.045
<i>ERS9</i>	Mississippi Portal	+ −	+ −	0.365
<i>ERS6^a</i>	Southern Seaboard	+ −	+ −	0.503

^aReference region

Table 3. Comparison of Characteristics between Adopters and Non-Adopters of Precision Soil Sampling

Variable ^a	Adopter Mean	Non-Adopter Mean	T-value ^{bc}
<i>LIVEST</i>	0.27	0.27	0.01
<i>PROFIT</i>	0.66	0.46	5.81**†
<i>ACRES</i>	1020	650	4.97**†
<i>OCROPS</i>	0.26	0.22	-2.28**†
<i>LANDTEN</i>	31.88	30.60	0.58
<i>YVAR</i>	545.61	506.73	2.16**†
<i>AGE</i>	47.87	50.59	-3.46**†
<i>EDUC</i>	14.73	13.99	4.80**
<i>COM</i>	0.67	0.51	5.12**
<i>INCOME</i>	0.38	0.30	2.41**†
<i>EXTEN</i>	0.59	0.54	1.52*†
<i>YRADOPT</i>	10.19	0.00	16.97**†
<i>VRPKL</i>	0.40	0.07	11.35**†
<i>n</i>	335	492	

^a Variables are defined in Tables 1 and 2.

^b Significance at the 5% and 10% levels denoted by **, and * respectively.

^c T-test assuming unequal variance denoted by †.

Table 4. Comparison of Characteristics of Producers Who Abandoned and Producers who Continued the use of Precision Soil Sampling

Variables ^a	Abandon Mean	Continue Mean	T-value ^{bc}
<i>LIVEST</i>	0.30	0.27	0.53
<i>PROFIT</i>	0.79	0.64	2.37**†
<i>ACRES</i>	1394	943	1.64*†
<i>OCROPS</i>	0.31	0.25	-1.72**†
<i>LANDTEN</i>	33.19	31.61	0.33
<i>YVAR</i>	548.66	545.00	0.09
<i>AGE</i>	48.32	47.78	0.38†
<i>EDUC</i>	14.39	14.80	-1.93*†
<i>COM</i>	0.75	0.67	1.18†
<i>INCOME</i>	0.52	0.35	2.30**
<i>EXTEN</i>	0.88	0.86	0.22
<i>YRAADOPT</i>	3.70	11.70	-7.48**†
<i>VRPKL</i>	0.39	0.40	-0.17
<i>n</i>	56	279	

^a Variables are defined in Tables 1 and 2.

^b Significance at the 5% and 10% levels denoted by **, and * respectively.

^c T-test assuming unequal variance denoted by †.

Table 5. Wald Test for Joint Significance of Residuals of Hypothesized Exogenous Variables

Model	Wald statistic	Critical χ^2 statistic ^c
<i>ADOPT</i> ^a	7.68	11.07
<i>ABANDON</i> ^b	7.52	14.07

^a *ADOPT* equals one if the farmer adopted precision soil sampling and zero otherwise.

^b *ABANDON* equals one if the farmer abandoned precision soil sampling and zero otherwise.

^c Degrees of freedom for the *ADOPT* and *ABANDON* models were 5 and 7 respectively

Table 6. Results from estimation of Adoption and Abandonment Equations.

Independent Variable ^b	Dependent Variable ^a			
	ADOPT		ABANDON	
	Probit Coefficient	Marginal Effect	Probit Coefficient	Marginal Effect
Constant	-1.932**	-0.746**	-4.258**	-0.703**
<i>LIVEST</i>	-0.073	0.028	0.118	0.020
<i>PROFIT</i>	0.321**	0.123**	0.378	0.058*
<i>ACRES</i>	0.213**	0.082**	0.200**	0.032**
<i>OCROPS</i>	0.303*	0.117*	0.650*	0.108*
<i>LANDTEN</i>	0.002	0.001	0.000	0.000
<i>YVAR</i>	0.000	0.000	0.000	0.000
<i>AGE</i>	0.017	0.007	0.169**	0.026**
<i>QUADAGE</i>	0.000	0.000	-0.002**	0.000**
<i>EDUC</i>	0.057**	0.022**	-0.030	-0.008
<i>COM</i>	0.183*	0.070*	0.265	0.038
<i>INCOME</i>	0.153	0.059	0.283	0.045
<i>EXTEN</i>	-0.028	-0.011	0.002	0.000
<i>YRADOPT</i>			-0.073**	-0.012**
<i>VRPKL</i>			-0.387*	-0.064**
<i>ERS1</i>	0.291	0.115	0.305	0.060
<i>ERS5</i>	0.303	0.120	-1.136**	-0.095**
<i>ERS7</i>	-0.033	-0.126	0.197	0.037
<i>ERS9</i>	0.135	0.052	-0.353	-0.056
<i>N</i>	827		335	
Unrestricted Log-likelihood	-512.881		-117.736	
Restricted Log-likelihood	-558.239		-151.206	
Likelihood ratio statistic ^d	90.717**		66.941**	
Correctly predicted	539 (65%)		285 (85%)	
Critical χ^2 statistic ^e	22.362**		27.587**	

^a ADOPT equals one if the farmer adopted precision soil sampling and zero other wise, ABANDON equals one if the farmer abandoned precision soil sampling and zero otherwise.

^b Independent variables are defined in Tables 1 and 2.

^c Significance at the 5% and 10% levels denoted by **, and * respectively.

^d Likelihood ratio statistic is $LR=2(\log\text{-likelihood unrestricted} - \log\text{-likelihood restricted})$ (Wooldridge 2006).

^e Degrees of freedom for the ADOPT and ABANDON models were 13 and 17 respectively.

Table 7. Percentage Distribution of Observations Used in Precision Soil Sampling Adoption/Abandonment Equations by State and Farm Resource Regions

State	Farm Resource Region				
	<i>ERS1</i> ^a	<i>ERS5</i>	<i>ERS6</i>	<i>ERS7</i>	<i>ERS9</i>
State	Percentage of Total Observations				
<i>TN</i>		0.37			8.46
<i>VA</i>			2.99		
<i>GA</i>			17.04	1.24	
<i>NC</i>			17.66		
<i>SC</i>			4.98	1.24	
<i>AL</i>		4.73	6.84		
<i>MS</i>			0.25		12.69
<i>LA</i>			0.50		6.84
<i>FL</i>				1.87	
<i>MO</i>	3.48				
<i>AR</i>					8.58
Total	3.48	5.10	50.25	4.36	36.57

^a *ERS1* is Heartland, *ERS5* is Eastern Uplands, *ERS6* is Southern Seaboard, *ERS7* is Fruitful Rim, *ERS9* is Mississippi Portal

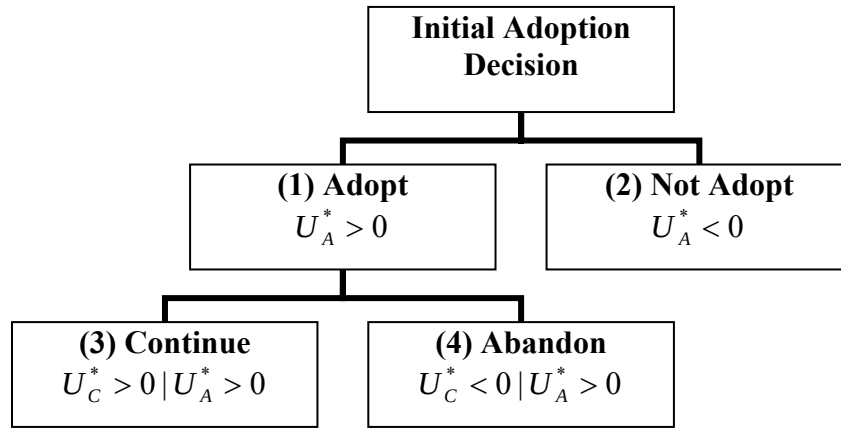


Figure 1. Precision Soil Sampling Decision Sequence

**Part 3: PDA and Handheld GPS Adoption in Precision Cotton
Production**

Introduction

Advances in information technologies used in precision agriculture have increased the degree at which spatial variation in cropland and crop performance can be measured. Technologies that can be used to measure spatial variation include grid or management zone soil sampling and yield monitors. In addition to the information technologies that have been specifically developed to collect precision farming data, a number of other more broad-based information management technologies are playing an increasingly important role in precision farming. For example, remotely sensed satellite and aerial imagery has been adopted for many agricultural crop management decisions. In addition, personal digital assistants (PDA) and other handheld computers utilizing the global positioning system (GPS) are being used by farmers to facilitate the handling of precision farming data such as remotely sensed images, yield maps, and soil maps. PDA/handheld GPS devices are also being used to collect additional field information to augment existing soil and yield maps and to act as a controller for variable-rate technology (VRT) application of inputs. Thus these handheld devices have a great deal of potential in farm management and agricultural production decision making. Notwithstanding the potential benefits of these technologies, site-specific management of farm fields is more management intensive compared to traditional whole-field management because of increased time and skill required for such activities as data collection, verification, interpretation, analysis, and implementation. This research focuses on the uses of PDA and handheld GPS devices in precision cotton production and the factors influencing adoption of these devices by farmers.

To understand the roles of PDA/handheld GPS devices in precision agriculture, it is appropriate to examine the general role of computers in farm management. The development of affordable, efficient computer technology has facilitated the handling and manipulation of large amounts of data. Extensive research has been conducted analyzing the farm and farmer characteristics associated with the adoption of computers in agriculture (e.g. Putler and Zilberman 1988; Batte, Jones, and Schnitkey 1990; Amponsah 1995). These studies found that computer adoption in agriculture was influenced by characteristics such as farm size, farmer education, and farmer age. Putler and Zilberman (1988) indicated that the use of computers for business transaction and accounting purposes was much higher than for use in decisions directly tied to production. However, the development of portable computing devices that can be used in precision agriculture since the completion of their study warrants an examination into the use of computer technology as an in-field decision-aid in production.

In precision agriculture, site-specific information technologies such as grid soil sampling, yield monitoring, and remote sensing are needed to collect spatially oriented crop and soil data. After an evaluation of the data using computer applications assisted by geographic information systems (GIS), decisions can be made to address potentially problematic areas of a farm field. For example, two information gathering technologies that require the use of additional technology for handling and manipulating data are remotely sensed crop images and maps created from yield monitoring data.

Understanding adoption of these technologies improves understanding of the adoption of PDA/handheld GPS devices. Larson et al. (2007) found that younger, more educated farmers operating larger acreages were more likely to adopt remotely sensed images for

making variable-rate application decisions. The use of computers in fields by farmers was a significant factor influencing adoption of remotely sensed imagery. Their study also emphasized the importance of farmers who generate their own variable-rate application prescriptions using computers and their use of a crop consultant to the adoption of remotely sensed crop images. Also emphasized was the importance that PDA/handheld GPS devices have in the overall remote sensing adoption package for cotton farmers. Remotely sensed crop images can be used to support input application decisions such as irrigation or fertilization (Broner et al. 2002). Images have also been used to map and classify soils (Zhai et al. 2006).

Cotton yield monitor adoption has lagged that of other crops (Griffin et al. 2004). The lag in adoption is the result of problems encountered during development (Wolak et al. 1999). Improvements since 2000 have solved many of the reliability and accuracy issues surrounding cotton yield monitors (Perry et al. 2001). These improvements have allowed the creation of lint yield maps using data obtained from yield monitors to accurately measure in-field yield variability.

While information technologies such as remotely sensed imagery and yield monitors have increased the efficiency with which problems are identified, the source of problems and accurate prescriptions to solve them often require physical inspection or “ground truthing” of fields accomplished through scouting. The integration of GPS technology with information gathering technologies has provided a means for geographically referencing potential problem areas within a field. The adaptation of handheld computers and PDA to include GPS capabilities has allowed guided scouting of field areas identified as potentially problematic by information technologies. The John

Deere Opti-Grow system incorporates the use of a PDA to ground truth fields prior to variable-rate application (Brown and Wesch 2006). Handheld computers and PDAs with GPS capability have been used to verify the accuracy of spatially oriented field data in precision agriculture as well as aid in the transmission of data. Guided scouting using remotely sensed maps loaded onto a PDA with GPS capabilities has been successful in increasing the efficiency and success of applications of insecticide, growth regulators, and harvest aids in cotton production (Robinson 2007). PDAs are also used as a link to feed prescription maps to controllers on VRT applicators (Robinson 2007; Brown and Wesch 2006; Yule, Lawrence, and Murray 2005; Muzzi 2004).

McKinnon et al. (2004) examined the possibility of using a wireless local area network to connect a PDA capable of handling spatially referenced data to variable-rate application equipment and cotton pickers. Limits on existing communication infrastructure make the transmission of some types of time sensitive data inefficient if not impossible. Their study looked at the transmission of multispectral images used in variable rate application of inputs in cotton production. After transmission through the wireless local area network, images were carried to the field using PDAs for the purpose of ground-truthing.

In their study of techniques to improve pasture production and management in New Zealand dairy farms, Yule, Lawrence, and Murray (2005) used a GPS enabled PDA as a user interface when measuring forage yield in dairy pastures. The use of a PDA coupled with sampling equipment mounted on an all terrain vehicle allowed for increased pasture sampling accuracy. In addition, spatially coordinated pasture yield data from the sampling procedure stored in the PDA could be used to generate variable rate application

maps for inputs such as fertilizer. PDAs with GPS capabilities have enabled geographically referenced yield monitoring in situations where conventional yield mapping technologies used in grain and cotton production will not work. Illinois State University conducted field trials comparing the performance corn planted in twin-rows to corn planted in conventional thirty inch rows (Fischer 2007). A self propelled forage harvester equipped with a PDA was used to spatially reference each load of ensilage harvested. After weighing each load, the data stored in the PDA could be used to control for differences in soil type throughout the field in comparing yield from different row spacings and plant populations. PDAs have also been combined with plant mapping programs for cotton to collect characteristics of the growing crop. Plant mapping and yield monitor data have been used for ground-truthing remotely sensed imagery (Plant et al. 2000).

Currently little research has been conducted to examine the economic factors that influence the adoption of handheld computers and PDA with GPS capability. The objective of this research was to identify the farm and farmer characteristics that affect the adoption of handheld computers and PDA with GPS capabilities. An understanding of these factors has applications for agribusiness firms engaged in the development and promotion of precision agricultural technologies as well as for Extension personnel developing educational curricula and support programs for farmers engaged in precision agriculture.

Data

The data was gathered from a survey of cotton producers in Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, Missouri, North Carolina, South Carolina,

Tennessee, and Virginia (Roberts et al. 2005). The survey questionnaires were mailed on January 28, 2005. Reminders and follow-up mailings were sent on February 4, 2005, and February 23, 2005. Of 12,243 surveys mailed, 200 were returned either undeliverable or by farmers indicating they were not cotton producers. A total of 12,043 cotton farmers were left in the sample after these exclusions. 1,216 cotton producers responded to the questionnaire giving a response rate of 10%. Producers responded to the survey providing information about the extent to which precision agricultural technologies were used on their farms as well as information on the general structure and characteristics of their farming operations. Producers answered questions concerning their opinions on the costs and profitability of precision agriculture as well as their perceptions of the future viability of precision agriculture. Producers reported the total number of years that a PDA/handheld GPS device was used to make different variable-rate management decisions. This information was then used to measure the level of PDA/handheld GPS adoption as well as examine the decisions that were made using a PDA/handheld GPS device. A total of 764 observations were available for analysis of PDA and handheld computer adoption after eliminating observations with missing data. Selected comparisons of this data to the 2003 United States Department of Agriculture Agricultural Resource Management Survey (ARMS) were used to determine the degree to which the data used represented cotton farmers nationwide.

Methods and Procedures

Analytical Framework

Farmers are assumed to make decisions to maximize expected utility. Due to the unobservable nature of utility, a random utility model is used to analyze the farmer's decision to adopt a PDA/handheld GPS device (Kennedy, 1992). Let U_A represent the expected utility from adopting a PDA/handheld GPS device and U_{NA} represent the expected utility from not adopting a PDA/handheld GPS device. Thus, an individual farmer's utility as $U_i = U_A - U_{NA}$, the farmer is expected to adopt a PDA/handheld GPS device when $U_i > 0$, and not adopt a PDA/handheld GSP device when $U_i < 0$.

Utility for farmer i is given by:

$$(1) U_i = \beta x_i + \varepsilon_i,$$

and is hypothesized to be a function of exogenous variables (x_i) and parameters (β) with random errors (ε_i). While U_i is unobservable, the observed farmer's decisions to adopt can be represented by a binary variable (Khanna 2001);

$$(2) A_i = 1 \text{ (if } U_A > U_{NA} \text{); else } A_i = 0 \text{ (if } U_A < U_{NA} \text{)}$$

Multiplication of the unobserved variable U_i by any positive constant does not change the interpretation of A_i . Thus, it is common to assume that the variance of the error term $Var(\varepsilon_i) = 1$ following the assumptions associated with standard normal distributions, $\mu = 0$ and $\sigma^2 = 1$. Under this assumption the relationships between equations (1) and (2) yield

$$\begin{aligned}
P_i &= \Pr(A_i = 1) \\
&= \Pr(U_i > 0) \\
(3) \quad &= \Pr[\varepsilon_i > -(\beta x_i)] \\
&= 1 - \Phi_i[-(\beta x_i)]
\end{aligned}$$

where P_i is the probability of adoption, $\Pr(I_i = 1)$ is the probability of positive response to the adoption question, and Φ_i is the cumulative distribution function for ε_i (Maddala 1988). The symmetric qualities of the standard normal distribution can be used to show that:

$$(4) \quad 1 - \Phi_i[-(\beta x_i)] = \Phi_i(\beta x_i).$$

Relating equation (3) to equation (4) shows the probability of adoption as:

$$(5) \quad P_i = \Phi_i(\beta x_i).$$

Given the probability stated in equation (5), the sample likelihood function can be written as:

$$(6) \quad L = \prod_{A_i=1} \Phi_i(\beta x_i) \prod_{A_i=0} \Phi_i(-\beta x_i).$$

The method of maximum likelihood can be used to determine parameter estimates. Parameter estimates can be used to predict the probability of adoption. Identification of characteristics influential to the adoption decision can be determined by the sign and significance of the parameter estimates and the evaluation of marginal probabilities estimated using the estimated parameters (Kennedy 1992).

Comparison of Sample Means

Comparisons of characteristics between the different population subsets were made to provide further insight into the factors motivating adoption. Adopters of PDA/handheld GPS devices were compared with those who did not adopt. An F test was

used to determine if the variances of each subset were significantly different. The means for each of the observed farm and farmer characteristic variables were compared using an appropriate t test assuming equal or unequal variances depending on the results of the F test.

Use of PDA/Handheld GPS Devices for Variable-Rate Decisions

Farmers who adopted a PDA/handheld GPS device were asked to identify each variable-rate management decision which involved the use of these devices. Mean percentages of use for each variable-rate decision were calculated to determine the importance of PDA/handheld GPS devices to different management decisions.

Empirical Adoption Model

The model for the adoption of PDA/handheld GPS devices was specified as follows:

(7)

$$\begin{aligned} PDA_k = & \beta_0 + \beta_1 LIVEST_k + \beta_2 ACRES_k + \beta_3 OCROPS_k + \beta_4 LANDTEN_k + \beta_5 YVAR_k \\ & + \beta_6 LOGAGE_k + \beta_7 EDUC_k + \beta_8 COM_k + \beta_9 INCOME_k + \beta_{10} EXTEN_k + \beta_{11} COTMAN_k \\ & + \beta_{12} RMSENS_k + \beta_{13} YIELDMON_k + \beta_{14} VRPKL_k + \beta_{15} VRDEFOL_k + \beta_{16} VRINSGR_k \\ & + \beta_{17} SELF_k + \beta_{18} CONSULT_k + \beta_{19} DEALER_k + \beta_{20} SOILMAP_k + \beta_{21} GRIDSOIL_k + \\ & \beta_{22} ZONESOIL_k + \beta_{23} ERS1_k + \beta_{24} ERS5_k + \beta_{25} ERS7_k + \beta_{26} ERS9_k + e_k, \end{aligned}$$

where PDA equals one if the farmer adopted a PDA or handheld GPS device and zero otherwise, β_1 through β_{26} are parameters to be estimated using maximum likelihood, e is the random error term, and k is the k th farmer in the dataset. Definitions of independent variables along with means and hypothesized signs can be found in Tables 1 and 2.

Hypotheses

Five farmer characteristics were hypothesized to affect the adoption decisions of cotton farmers (Table 1). The natural log of farmer age (LOGAGE) was expected to be negatively associated with adoption of a PDA/handheld GPS device. As age increases, the farm decision maker's planning horizon decreases which limits the period of time in which farmers perceive they can make changes and offset learning costs (Batte, Jones, and Schnitkey 1990; Roberts et al. 2004). The logarithmic transformation of the linear age variable serves to capture the effect of changes in the rate of adoption over the lifespan of the farmer. The number of years of formal education (EDUC) was expected to positively influence adoption. Higher levels of formal education may facilitate the analytical ability of farm decision makers dealing with the volume and intricacy of data associated with precision agriculture (Batte, Jones, and Schnitkey 1990). In much the same way, the use a computer in farm management (COM) is expected to positively influence adoption. Because computer technology is either integrated into precision agricultural technology or it is necessary to convey and manipulate precision farming data, computer use for farm management is likely tied to PDA/handheld GPS adoption decisions through previous experience with computers (Daberkow and McBride 1998). Higher income levels (INCOME) are expected to be positively related to adoption. Due to the substantial costs associated with some precision farming technologies, higher income could improve the farmer's ability to investment in more advanced electronic technologies (Rogers 1983; Daberkow and McBride 1998). Farmers who felt that Extension was helpful in making precision farming decisions (EXTEN) were expected to be more likely to adopt a PDA/handheld GPS device. The availability of services such as

Extension provides information to the farmer in investment decision making decisions. These services may have the ability to reduce some of the perceived risk associated with adoption.

The following characteristics of the farm operation were hypothesized to influence adoption of PDA/handheld GPS devices (see table 1). The number of cotton acres planted (ACRES) represents a measure of enterprise size and is hypothesized to be positively related to adoption. If the fixed costs associated with computer technologies can be spread over a larger crop area, the barriers to adoption will be less prohibitive (Roberts et al. 2004; Fernandez-Cornejo, Beach, and Huang 1994; Putler and Zilberman 1988). Similarly, learning costs associated with adoption may be spread over a larger number of acres increasing the probability of adoption (Batte and Johnson 1993). Farmers who have larger cotton acreages are also expected to have a greater need for technology to facilitate the handling of large amounts of spatially-oriented data associated with the crop area. The percentage of total cropped acres devoted to other crops (OCROPS) is expected to positively influence adoption. Farmers who place greater emphasis on crops such as grains and oilseeds are expected to transfer the use of precision agricultural technologies from those crops to cotton. An enterprise mix that includes cotton along with other crops which have higher precision agriculture adoption rates could influence the adoption of technologies in cotton production (Griffin et al. 2004). Enterprise diversification, represented by livestock ownership (LIVEST), is expected to negatively influence adoption. Fernandez-Cornejo, Beach, and Huang (1994) found that livestock production had a significant negative impact on the adoption of integrated pest management. Management of an enterprise that is not directly related to

crop agriculture could reduce the operator's ability to devote time to managing crop performance. The percentage of total cropped acres that is owned (LANDTEN) is hypothesized to be positively related to adoption. Farmers are likely to apply more management attention to owned land than rented land because the management of owned land may be expected to fall to subsequent generations (Roberts et al. 2004). Some spatially referenced data may be utilized in multiple growing seasons. Ownership of land helps insure that data obtained from an investment in technology will be applicable to multiple growing seasons (Daberkow and McBride 1998). Spatial yield variability (YVAR) is hypothesized to be positively related to adoption. The presence of greater yield variability increases the level of management intensity and the level of variability in required inputs. Technologies that increase management efficiency and input application efficiency can enhance profitability (Larson and Roberts 2004).

PDA/handheld GPS devices may be complementary to other information technologies such as remote sensing , yield monitoring, plant mapping, and precision soil sampling (Barham et al. 2004). Consequently the farmer's use of these and other information technologies were specified as variables in the model to help explain adoption of PDA/handheld GPS devices. The use of remote sensing (RMSSENS), yield monitors (YELDMON), and plant mapping (COTMAN) to gather crop data are expected to positively influence the adoption of PDA/handheld GPS devices. Technologies used to generate maps of spatial variation in a field may require ground truthing using technologies such as PDA/handheld GPS devices to identify problems and generate spatially coordinated input prescriptions (Robinson 2007). The use of soil survey maps (SOILMAP) is expected to positively influence the adoption of PDA/handheld GPS

devices. Knowledge of in-field variation in soil type has the potential to be augmented by technology that enables more intensive ground-truthing. Precision soil sampling whether by grid (GRIDSOIL) or management zone (ZONESOIL) is expected to increase the probability of PDA/handheld GPS adoption. Technologies and practices driven by site-specific data could benefit from the use of additional technologies which enable spatially referenced ground-truthing.

As indicated earlier maps in PDAs with GPS are used to guide the scouting of fields for variable-rate application of certain inputs in cotton (Robinson, 2007). Thus several explanatory variables indicating that adopters were using selected variable-rate input technologies were also included in the logit model. Variable-rate application of phosphorus, potassium, and lime (VRPKL) is expected to positively influence the adoption of a PDA/handheld GPS device. The use of variable-rate application of other inputs such as defoliant (VRDEFOL), insecticides, and plant growth regulators (VRINSGR) are expected to positively affect adoption. Variable-rate application of these inputs requires not only geographically referenced ground-truthing but geographically referenced control of the variable-rate application procedure. The source of the maps used to make variable-rate applications of inputs may also play a role in the adoption of a PDA/handheld GPS device. Farmers who generate their own maps for variable-rate application (SELF) are expected to have a higher probability of adoption. The handling of spatially referenced field and crop data may be facilitated by the use of a PDA of handheld GPS device. Farmers who obtain maps for variable-rate application from consultants (CONSULT) or fertilizer or chemical dealers (DEALER) are expected to have a higher probability of adoption. Farmers may feel the need to audit the input

application recommendations provided by outside entities. A PDA/handheld GPS device would facilitate this process.

Location variables in the form of USDA Economic Research Service farm resource regions (See table 2) were included in the PDA/handheld GPS adoption model to test if cotton producers in the Heartland (ERS1), Eastern Uplands (ERS5), Fruitful Rim (ERS7), and Mississippi Portal (ERS9) regions had higher or lower probabilities of adopting precision soil sampling than cotton producers in the Southern Seaboard (ERS6) region (U. S. Department of Agriculture-Farm Resource Regions 2007). The Southern Seaboard region was chosen for comparison because it had the largest number of survey responses. Percentage distribution of observations by state and farm resource region is contained in Table 7.

Exogeneity Tests

The potential exists for endogenous relationships between certain farm and farmer characteristics and the decision to adopt a PDA/handheld GPS device. Complementary relationships between technologies and practices can affect farmer perceptions of the expected value of a decision (Barham et al. 2004). Variables in the PDA/handheld GPS adoption equation that were hypothesized to be potentially endogenous include cotton acreage (ACRES), percentage of total cropped acreage devoted to other crops (OCROPS), yield variability (YVAR), computer use in farm management (COM), household income above \$150,000 (INCOME), use of remote sensing (RMSENS), use of a yield monitor (YELDMON), use of plant mapping (COTMAN), variable-rate application of phosphorus, potassium, and lime (VRPKL), variable-rate application of insecticide and grow regulator (VRINSGR), variable-rate application of defoliant

(VRDEFOL), use of soil survey maps (SOILMAP), soil sampling by grid (GRIDSOIL), and soil sampling by management zone (ZONESOIL). These variables were hypothesized to be potentially endogenous because variation in these variables could result from the PDA/handheld GPS adoption decision. The use of a PDA/handheld GPS device could facilitate the management of larger acreages and increase the efficiency of management decisions which could lead to lower yield variability. Data handled in a PDA/handheld GPS is often first manipulated and transferred through other types of computer technology. Uncertainty concerning the possibility that the computer-use decision was to facilitate the use of PDA/handheld GPS is a potential source of endogeneity. The use of a PDA/handheld GPS device has the potential to increase management efficiency increasing profit and thus increasing income reported by the producer. Increases in the efficiency of data handling incurred through the adoption of a PDA/handheld GPS device may result in decisions to adopt variable-rate application of inputs or more intensive soil analysis methods.

Testing for exogeneity of these variables was accomplished using a procedure outlined by Rivers and Vuong (1988). In this procedure, each potentially endogenous variable was regressed against all other exogenous variables and a vector of instrumental variables. The residuals from each of these equations were then included as additional explanatory variables in a separate estimation of the adoption equations. Generalized residuals were calculated for potentially endogenous binary variables (Vella 1992). The residuals were tested for joint significance using a Wald test (Wooldridge 2002). Failure to reject the null hypothesis of joint significance provides evidence that the variables are exogenous.

Multicollinearity Tests

The presence of collinear relationships among explanatory variables can influence the significance and inferential power of coefficients. Variance inflation factors were used to detect the presence of these collinear relationships. Variance inflation factors were calculated using the squared multiple correlation coefficient from the regression of each explanatory variable on all other explanatory variables. As the degree of variation in each individual explanatory variable explained by all other explanatory variables increases, the value of the variance inflation factor increases. Variance inflation factors with a value greater than 10 are often thought to indicate the presence of collinearity in the data (Chatterjee and Price, 1991).

Model Estimation

Equation (9) was estimated using logistic regression. Due to the nature of the data there is reason to suspect the presence of non-constant variance of the variables used in the adoption equation. Methods described by White (1980) were used obtain heteroscedasticity-robust standard errors. Overall significance of the model was tested using a likelihood ratio test.

Results

Evaluation of Data

Comparison of these data to data from the 2003 United States Department of Agriculture Agricultural Resource Management Survey (ARMS) is a necessary caveat when considering the degree to which the results of this research represent cotton producers in the United States. Results of the 2003 ARMS show that 25% of cotton producers attended at least some college while the results of the survey data used in this

research indicate that 53% of cotton producers attended at least some college. The ARMS survey reports an average of 501 acres of cotton per farm. The data from Roberts et al. (2005) used here reports an average of 818 acres of cotton per farm. Percentage of total income from farming averaged 45% in the ARMS data while the data used here show an average of 73% of total household income coming from farming (U.S. Department of Agriculture- ARMS 2007). Differences between the sample used here and the ARMS sample suggest that inferences to the general population of cotton farmers in the 11 states may not be appropriate and that farmer with certain characteristics may be underrepresented, but useful information can be obtained about the factors that influence adoption for this sample.

Comparison of Sample Means

Comparison of means of the observed farm and farmer characteristic variables for the population subsets of adopters and non-adopters indicates that adopters were significantly different from non-adopters in all measures except livestock ownership (LIVEST), percentage of total crops acres devoted to crops other than cotton (OCROPS), and land tenure (LANDTEN) (see Table 3). Results of the comparison indicate that adopters were younger, had more optimistic perceptions about the future profitability of precision farming, farmed larger cotton acreages, reported higher spatial yield variability, utilized computers more heavily in farm management, and reported higher levels of income. The results also indicate that non-adopters felt more strongly that Extension should provide greater precision farming outreaches than adopters. The use of other precision farming technologies was also significantly higher among adopters than non-adopters.

PDA/Handheld GPS Use

Results of the analysis PDA/handheld GPS device use in making variable-rate decisions is reported in Table 4. Variable-rate application of fertilizer and lime and the identification of management zones had the highest percentages of use. These were followed by use of a PDA/handheld GPS device in dealing with drainage issues and the variable-rate application of growth regulator and harvest aids.

Model Evaluation

Variance inflation factors for all variables were under 3 indicating multicollinearity was not likely to interfere with the interpretation of the parameter estimates. Results of the likelihood ratio test indicated rejection of the null hypothesis that all regression coefficients were equal zero. This result showed that the model was significant overall at a 5% level. The model correctly predicted 37 (43%) of the positive adoption responses. The test for exogeneity failed to reject the hypothesis of statistical exogeneity of the hypothesized variables at the 5% level (Table 5). While these tests demonstrate that endogenous variables do not statistically harm the results of the estimation, the potential for economic endogeneity is noted in the relationships of these variables to the choice variable being analyzed.

PDA/Handheld GPS Adoption

Results from the estimation of the adoption equation can be seen in Table 6. Higher levels of yield variability (YVAR), computer use in farm management (COM), use of remotely sensed images (RMSSENS), plant mapping (COTMAN), variable-rate application of phosphorus, potassium, and lime (VRPKL), variable-rate application of insecticide and plant growth regulator (VRINSGR), and grid soil sampling (GRIDSOIL)

all contributed significantly to the probability of adopting a PDA/handheld GPS device. Signs of these variables were consistent with those previously hypothesized. Farmer Age (LOGAGE) and positive perceptions about the usefulness of Extension in making precision farming decisions (EXTEN) also significantly affected adoption. Livestock ownership (LIVEST), land tenure (LANDTEN), size of the cotton enterprise (ACRES), percentage of total cropped acreage devoted to crops other than cotton (OCROPS), education (EDUC), income (INCOME), the use of yield monitor (YIELDMON), variable-rate application of defoliant (DEFOL), farmer generation of application maps (SELF), fertilizer or chemical dealer generation of application maps (DEALER), the use of a consultant to generate maps for input application (CONSULT), the use of soil survey maps (SOILMAP), and soil sampling by management zone (ZONESOIL) did not significantly affect the probability of adopting a PDA/handheld GPS device.

These results indicate that younger farmers who perceive that precision agriculture will be profitable in the future have a higher probability of adopting a PDA/handheld GPS device. The presence of greater yield variability and the use of remotely sensed crop images, plant mapping, variable-rate application of certain inputs, and soil sampling by grid also increase the probability of adoption. These findings are consistent with existing adoption literature upon which the basis of the previously stated hypotheses was formed.

Summary and Conclusion

Farmer decisions concerning the adoption of PDA or handheld GPS device in precision cotton production were analyzed in a framework of a random utility model. The results of the logistic regression suggest that younger farmers who reported greater cotton

yield variability were more likely to adopt a PDA/handheld GPS device for use in precision cotton production. The use of computers in farm management, remotely sensed images, plant mapping, variable-rate application of certain inputs, and grid soil sampling positively influenced the probability of adoption. These results highlight the significance of complementary relationships between PDA/handheld GPS use and other precision farming technologies and practices. Comparisons of means for each of the farm and farmer characteristic variables showed significant differences between adopters and non-adopters. The only characteristics for which adopters and non-adopters were not significantly different were the percentage of cropped acreage devoted to crops other than cotton, livestock ownership, and land tenure. Differences in number of significant variables affecting adoption shown in the results of the logistic regression and the comparison of samples means can be attributed to the effects of regression procedure holding all other characteristic variables constant while calculating the regression coefficient. Analysis of the use of PDA/handheld GPS devices in making variable-rate decisions demonstrated the level of importance of device use to different precision farming activities as well as which technologies were most likely to be complementary to the use of a PDA/handheld GPS device.

These findings have implications for agronomists and agribusiness firms involved in developing methods to assist in the implementation of precision farming practices. An understanding of the factors motivating adoption of a PDA/handheld GPS device in precision cotton production can provide insight into areas of potential improvement in the promotion of precision agriculture. Understanding the complementary precision agricultural tools and practices that motivate adoption also has the potential to illuminate

areas in which further product development could increase the efficiency of these products used cooperatively in a package of technologies.

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Appendix

Table 1. Variable Definitions, Hypothesized Signs, Means, and Standard Deviations in the PDA and Handheld GPS Adoption Equation

Variable	Definition	Hypothesized Sign	Mean	Std. Dev.
Farmer Characteristics				
<i>LOGAGE</i>	Natural log of age in years of the primary decision maker	–	3.86	0.24
<i>EDUC</i>	Number of years of formal education	+	14.35	2.21
<i>COM</i>	Equals one if the farmer uses a computer for farm management and zero otherwise	+	0.59	0.49
<i>EXTEN</i>	Equals one if the farmer felt that Extension was useful in making precision farming decisions	+	0.57	0.50
Farm Characteristics				
<i>ACRES</i>	Average cotton acreage grown in 2003 and 2004	+	817.70	966.64
<i>OCROPS</i>	Percentage of non-cotton acreage to total cropped acreage	+	23.73	27.12
<i>LIVEST</i>	Equals one if the farming operation includes livestock and zero otherwise	–	0.28	0.45
<i>LANDTEN</i>	Percentage of owned land to total land farmed	+	30.86	31.25
<i>YVAR</i>	Difference between the farmer's estimates of average yields for the most productive 1/3 of and the least productive 1/3 of a typical field	+	530.34	249.41
<i>INCOME</i>	Equals one if pre-tax household income is greater than \$150,000	+	0.33	0.47
Variable-Rate Application Decisions				
<i>VRDEFOL</i>	Equals one if variable-rate application of defoliant was used and zero otherwise	+	0.05	0.21

Table 1. Continued

Variable	Definition	Hypothesized Sign	Mean	Std. Dev.
<i>VRPKL</i>	Equals one if variable-rate application of P, K, or L was used and zero otherwise	+	0.21	0.41
<i>VRINSGR</i>	Equals one if variable-rate application of growth regulator or insecticide were used and zero otherwise	+	0.05	0.21
Complementary Technologies				
<i>RMSSENS</i>	Equals one if remote sensing was used to gather crop data	+	0.12	0.32
<i>YIELDMON</i>	Equals one if the farmer used a yield monitor and zero otherwise	+	0.10	0.31
<i>COTMAN</i>	Equals one if COTMAN plant mapping software was used and zero otherwise.	+	0.05	0.22
<i>SELF</i>	Equals one if the farmer generated maps to apply inputs and zero otherwise	+	0.03	0.17
<i>CONSULT</i>	Equals one if a consultant generated maps to apply inputs and zero otherwise	+	0.06	0.23
<i>DEALER</i>	Equals one if a fertilizer or chemical dealer generated maps to apply inputs and zero otherwise	+	0.09	0.29
<i>SOILMAP</i>	Equals one if the farmer used soil survey maps and zero otherwise	+	0.21	0.41
<i>GRIDSOIL</i>	Equals one if the farmer used grid soil sampling	+	0.22	0.41
<i>ZONESOIL</i>	Equals one if the farmer used management zone soil sampling	+	0.11	0.32

Table 2. Location Variables in PDA and Handheld GPS Adoption Equation

Variable	Definition	Hypothesized sign	Mean
Location Variables			
<i>ERS1</i>	Heartland	+ –	0.035
<i>ERS5</i>	Eastern Uplands	+ –	0.052
<i>ERS7</i>	Fruitful Rim	+ –	0.045
<i>ERS9</i>	Mississippi Portal	+ –	0.365
<i>ERS6^a</i>	Southern Seaboard	+ –	0.503

^aReference region

Table 3. Comparison of Characteristics between Adopters and Non-Adopters of PDA and handheld GPS devices

Variable ^a	Adopter Mean	Non-Adopter Mean	T-value ^{bc}
<i>LIVEST</i>	0.26	0.28	-0.35
<i>ACRES</i>	1447.74	736.75	3.59**†
<i>OCROPS</i>	0.27	0.23	1.70
<i>LANDTEN</i>	30.36	30.93	-0.16
<i>YVAR</i>	627.55	517.85	3.90**
<i>LOGAGE</i>	3.76	3.88	-3.78**†
<i>EDUC</i>	14.84	14.28	2.21**
<i>COM</i>	0.84	0.56	6.38**†
<i>INCOME</i>	0.44	0.32	2.26**
<i>EXTEN</i>	0.70	0.55	-2.70**
<i>COTMAN</i>	0.18	0.04	-3.50**†
<i>VRPKL</i>	0.59	0.17	7.65**†
<i>VRDEFOL</i>	0.20	0.03	3.83**†
<i>VRINSGR</i>	0.22	0.03	4.30**†
<i>RMSENS</i>	0.31	0.09	4.28**†
<i>YELDMON</i>	0.33	0.08	4.91**†
<i>SELF</i>	0.10	0.02	2.49**†
<i>CONSULT</i>	0.18	0.04	3.36**†
<i>DEALER</i>	0.20	0.08	2.70**†
<i>n</i>	87	677	

^a Variables are defined in Tables 1 and 2.

^b Significance at the 5% and 10% levels denoted by **, and * respectively.

^c T-test assuming unequal variance denoted by †.

Table 4. Uses of PDA/handheld GPS devices by Variable-rate Input Application Decision

Variable Rate Decision	Percentage of use
<i>Identify Zones</i>	56.32
<i>Drainage</i>	20.69
<i>Fertility or Lime</i>	66.67
<i>Seeding</i>	8.04
<i>Growth Regulator</i>	20.69
<i>Harvest Aids</i>	14.94
<i>Fungicide</i>	3.45
<i>Herbicide</i>	11.49
<i>Insecticide</i>	12.64
<i>Irrigation</i>	10.34
Number of Adopters	87

Table 5. Wald Test for Joint Significance of Residuals of Hypothesized Exogenous Variables

Model	Wald statistic	Critical χ^2 statistic ^b
<i>PDA</i> ^a	15.05	27.59

^a *PDA* equals one if the farmer adopted the use of a PDA or handheld GPS device and zero otherwise.

^b 17 degrees of freedom at a 5% level of significance

Table 6. Results from Estimation of the PDA/handheld GPS Adoption Equation

Independent Variable ^b	Dependent Variable ^a	
	PDA	Marginal Effect
Constant	−0.185	−0.009
<i>LIVEST</i>	0.138	0.007
<i>ACRES</i>	0.158	0.008
<i>OCROPS</i>	−0.170	−0.009
<i>LANDTEN</i>	0.000	0.000
<i>YVAR</i>	0.001**	0.001**
<i>LOGAGE</i>	−1.254*	−0.050*
<i>EDUC</i>	−0.031	−0.002
<i>COM</i>	0.650*	0.032*
<i>INCOME</i>	0.302	0.016
<i>EXTEN</i>	0.609**	0.030**
<i>COTMAN</i>	1.749**	0.181**
<i>YIELDMON</i>	0.058	0.003
<i>VRPKL</i>	1.059**	0.072**
<i>VRDEFOL</i>	−0.369	−0.016
<i>VRINSGR</i>	1.556**	0.150
<i>RMSENS</i>	0.855**	0.059*
<i>SELF</i>	0.481	0.030
<i>CONSULT</i>	0.772	0.054
<i>DEALER</i>	0.318	0.018
<i>SOILMAP</i>	0.148	0.008
<i>GRIDSOIL</i>	0.865**	0.056**
<i>ZONESOIL</i>	−0.095	−0.005
<i>ERS1</i>	0.066	0.003
<i>ERS5</i>	−0.286	−0.013
<i>ERS7</i>	−0.034	−0.002
<i>ERS9</i>	0.391	0.021
<i>n</i>	764	
Unrestricted Log-likelihood	−185.547	
Restricted Log-likelihood	−270.989	
Likelihood ratio statistic ^d	170.884**	
χ^2 statistic ^e	38.885**	
Correctly predicted	701(92%)	

^aPDA equals one if the farmer adopted a personal digital assistant or handheld GPS device and zero otherwise.

^bIndependent variables are defined in Tables 1 and 2.

^cSignificance at the 5% and 10% levels denoted by **, and * respectively.

^d Likelihood ratio statistic is $LR=2(\log\text{-likelihood unrestricted} - \log\text{-likelihood restricted})$

^e 26 degrees of freedom at a 5% level of significance.

Table 7. Percentage Distribution of Observations Used in PDA/Handheld GPS Device Adoption Equation by State and Farm Resource Regions

State	Farm Resource Region				
	<i>ERS1</i> ^a	<i>ERS5</i>	<i>ERS6</i>	<i>ERS7</i>	<i>ERS9</i>
State	Percentage of Total Observations				
<i>TN</i>		0.20			9.00
<i>VA</i>			2.88		
<i>GA</i>			17.15	1.31	
<i>NC</i>			17.41		
<i>SC</i>			4.45	1.31	
<i>AL</i>		4.71			
<i>MS</i>			0.20		12.70
<i>LA</i>			0.80		6.81
<i>FL</i>				1.83	
<i>MO</i>	3.66				
<i>AR</i>					8.25
Total	3.66	4.91	42.89	4.45	36.76

^a *ERS1* is Heartland, *ERS5* is Eastern Uplands, *ERS6* is Southern Seaboard, *ERS7* is Fruitful Rim, *ERS9* is Mississippi Portal

Part 4: Summary

Summary

This study presented an examination of the economic factors motivating decision makers involved in precision cotton production. Farmers were assumed to make technology adoption and abandonment decisions which would maximize their utility. The expected utility maximization assumption was used to hypothesize relationships between observable farm and farmer characteristics and adoption and/or abandonment decisions made by farmers.

The first portion of this study focused on the factors that influence adoption and subsequent abandonment of precision soil sampling in cotton production. Farm and farmer characteristics were identified that were hypothesized to influence adoption and abandonment decisions. Univariate analysis showed significant differences between adopters and non-adopters as well as those who abandoned and those who continued the use of precision soil sampling. Results from the estimation of probit models showed that farmers with larger cotton acreages were more likely to adopt. Positive perceptions about the future of precision agriculture as well as the use of computers in farm management increased the probability of adoption. Farmers who devoted a larger percentage of their acreage to crops other than cotton also had a greater probability of adoption.

Factors motivating abandonment were examined using methods similar to those used to examine adoption decisions. Because adoption is a prerequisite to abandonment, only farmers who had adopted precision soil sampling were included in the sample of farmers who could make the abandonment decision. Results indicated that younger farmers who had persisted in the use of precision soil sampling for a greater number of years were less likely to abandon. The use of variable-rate application of fertilizer and

lime also lowered the probability of abandonment. The size of cotton acreage was positively related to abandonment of precision soil sampling. Regional variables indicated that farmers in the Eastern Uplands farm resource region were less likely to abandon.

The second portion of this study focused on factors influencing the adoption of a precision agricultural technology that has received relatively little attention—the personal digital assistant (PDA) or handheld computer with global positioning systems (GPS) capabilities. The examination of a technology whose primary function is information handling and management was shown to have implications not only for the understanding of technology adoption behavior but also for the understanding of complementary relationships between technologies and practices. Examples of PDA/handheld GPS device use in precision agriculture were given to illustrate the different ways in which this technology eases the data handling demands in different areas of site-specific management and to provide evidence of technologies which had the potential to complement PDA/handheld GPS use.

Comparison of sample means of selected farm and farmer characteristics between population subsets of adopters and non-adopters provided an initial perspective on the factors influencing adoption. Logistic regression was then used to determine the degree to which each of these characteristics affected the probability of adoption, other things constant. Results showed that spatial yield variability of cotton and perceptions about the usefulness of Extension services in making precision farming decisions both positively affected the probability of adoption. Computer use in farm management also significantly affected the probability of PDA/handheld GPS device adoption. Precision farming

technologies and practices which were complementary to PDA/handheld GPS device adoption included remotely sensed images, plant mapping, grid soil sampling, and variable-rate application of inputs.

This study provided further insight into factors motivating decisions in the evolving field of precision agriculture. The findings contained in this research add to the existing body of economic literature in a significant way by explaining factors motivating technology adoption and abandonment behaviors with specific applications to precision agriculture and cotton production. Information gained through this study can be used to further educational efforts as well as research and development efforts involving precision agricultural technologies and practices.

Vita

Jonathan Core Walton was born in Knoxville, Tennessee, on April 18, 1982 to Donald and Wendy Walton. He graduated from William Blount High School in Maryville, Tennessee in 2000. He attended the University of Tennessee, Knoxville and received a B. M. in Music Education in 2004 and a M. S. in Agricultural Economics in 2007.