PDA and Handheld GPS Adoption in Precision Cotton Production

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Abstract

This research analyzed the adoption of Personal Digital Assistants (PDA) and handheld Global Positioning System (GPS) devices in cotton production. Analysis using a logit model found that younger farmers who used a crop consultant, remote-sensing, variable-rate fertilizer, and reported greater yield variability had a higher probability of adopting.

Keywords: Computer**s,** precision farming technology, variable rate technology.

JEL Classifications: D21, Q12, Q16.

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. 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. 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 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 for farm management and agricultural production decision making. 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 useful 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 analyzed 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. 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 producers farming relatively acres 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 generated 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 had 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 behind other crops (Griffin et al. 2004). The lag in adoption may be 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 of problem identification, the cause of such problems and potential solutions 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 John Deere Opti-Grow system incorporates the use of a PDA to ground truth fields prior to variable-rate application (Brown and Wesch 2006). Guided scouting using remotely sensed maps loaded into 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 to ling fertilizer 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 wireless local area networks to connect a PDA capable of handling spatially referenced data to variable-rate application equipment and cotton pickers. 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. 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 examined the economic factors that influence the adoption of handheld computers and PDA with GPS capability in production agriculture. 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). 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) $A_i = 1$ (if $U_A > U_{NA}$); else $A_i = 0$ (if $U_A < U_{NA}$),

where A_i represents the observable adoption decision.

Assuming a logistic distribution of random errors (ε_i) from equation (1), the probability of adoption can be represented by:

$$(3)\ P_A = \frac{e^{\beta x_i}}{1+e^{\beta x_i}},$$

and not adopting by:

$$(4)\ P_{NA} = \frac{1}{1+e^{\beta x_i}},$$

which yields the likelihood function:

$$(5)\ L = \prod \frac{e^{\beta x_i}}{1+e^{\beta x_i}} \prod \frac{1}{1+e^{\beta x_i}}.$$

Maximizing the likelihood function with respect to β produces the maximum likelihood estimator of β which when applied to equation (4) gives:

$$(6)\ \frac{P_A}{P_{NA}} = e^{\beta x_i},$$

and

$$(7)\ \ln\left(\frac{P_A}{P_{NA}}\right) = \beta x_i.$$

Equation (7) provides the basis for using logistic regression to determine parameter estimates which in turn can be used to estimate the probability of adoption (Kennedy 1992).

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

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

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 are 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 number of years of formal education (EDUC) was expected to positively influence adoption. Higher levels of formal education may increase 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 with adoption PDAs. 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. Such services may 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 owned (LANDTEN) is hypothesized to be positively related with adoption. Farmers are likely to apply more managerial attention to land they own because the owned land may be passed on 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 explain adoption of PDA/handheld GPS devices. The use of remote sensing (RMSENS), yield monitors (YIELDMON), 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 logistic regression 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 defoliants (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 be more likely to adopt a PDA/Handheld GPS device. Farmers may feel the need to audit input application recommendations provided by outside sources. A PDA/handheld GPS device could facilitate this process.

The USDA Economic Research Service farm resource regions 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 the reference group because it produced the largest number of survey responses.

Exogeneity Tests

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 ACRES, OCROPS, YVAR, COM, INCOME, RMSENS, YIELDMON, COTMAN, VRPKL, VRINSGR, VRDEFOL, SOILMAP, GRIDSOIL, ZONESOIL. 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. 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.

The null hypothesis that these variables were exogenous was tested using a procedure outlined by Rivers and Vuong (1988) and Wooldridge (2002).

Results

PDA/Handheld GPS Use

PDA/handheld GPS devices were most frequently used with variable-rate application of fertilizer and lime (67%) and the identification of management zones (56%). These were followed by use of a PDA/handheld GPS device in dealing with drainage issues (21%) and the variable-rate application of growth regulator (21%) and harvest aids (15%).

Model Evaluation

Results of the likelihood ratio test indicated rejection of the null hypothesis that all regression coefficients were equal zero at the 5% level. The test for exogeneity failed to reject the hypothesis of statistical exogeneity of the hypothesized variables at the 5% level (Wald Statistic= 15.05, Critical chi-square value= 27.59 with 17 degrees of freedom).

PDA/Handheld GPS Adoption

Higher levels of yield variability (YVAR), computer use in farm management (COM), use of remotely sensed images (RMSENS), 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 (Table 3). 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 of 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.

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. 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. 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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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				
LOGAGE	Natural log of age in years of the primary decision maker	−	3.86	0.24
EDUC	Number of years of formal education	+	14.35	2.21
COM	Equals one if the farmer uses a computer for farm management and zero otherwise	+	0.59	0.49
EXTEN	Equals one if the farmer felt that Extension was useful in making precision farming decisions	+	0.57	0.50
Farm Characteristics				
ACRES	Average cotton acreage grown in 2003 and 2004	+	817.70	966.64
OCROPS	Percentage of non-cotton acreage to total cropped acreage	+	23.73	27.12
LIVEST	Equals one if the farming operation includes livestock and zero otherwise	−	0.28	0.45
LANDTEN	Percentage of owned land to total land farmed	+	30.86	31.25
YVAR	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
INCOME	Equals one if pre-tax household income is greater than $150,000	+	0.33	0.47
Variable-Rate Application Decisions				
VRDEFOL	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.
VRPKL	Equals one if variable-rate application of P, K, or L was used and zero otherwise	+	0.21	0.41
VRINSGR	Equals one if variable-rate application of growth regulator or insecticide were used and zero otherwise	+	0.05	0.21
Complementary Technologies				
RMSENS	Equals one if remote sensing was used to gather crop data	+	0.12	0.32
YIELDMON	Equals one if the farmer used a yield monitor and zero otherwise	+	0.10	0.31
COTMAN	Equals one if COTMAN plant mapping software was used and zero otherwise.	+	0.05	0.22
SELF	Equals one if the farmer generated maps to apply inputs and zero otherwise	+	0.03	0.17
CONSULT	Equals one if a consultant generated maps to apply inputs and zero otherwise	+	0.06	0.23
DEALER	Equals one if a fertilizer of chemical dealer generated maps to apply inputs and zero otherwise	+	0.09	0.29
SOILMAP	Equals one if the farmer used soil survey maps and zero otherwise	+	0.21	0.41
GRIDSOIL	Equals one if the farmer used grid soil sampling	+	0.22	0.41
ZONESOIL	Equals one of the farmer used management zone soil sampling	+	0.11	0.32

Table 2. Results from Estimation of the PDA/handheld GPS Adoption Equation

	Dependent Variable[a]	
	PDA	
Independent Variable[b]	Coefficient[c]	Marginal Effect
Constant	–0.185	–0.009
LIVEST	0.138	0.007
ACRES	0.158	0.008
OCROPS	–0.170	–0.009
LANDTEN	0.000	0.000
YVAR	0.001**	0.001**
LOGAGE	–1.254*	–0.050*
EDUC	–0.031	–0.002
COM	0.650*	0.032*
INCOME	0.302	0.016
EXTEN	0.609**	0.030**
COTMAN	1.749**	0.181**
YIELDMON	0.058	0.003
VRPKL	1.059**	0.072**
VRDEFOL	–0.369	–0.016
VRINSGR	1.556**	0.150
RMSENS	0.855**	0.059*
SELF	0.481	0.030
CONSULT	0.772	0.054
DEALER	0.318	0.018
SOILMAP	0.148	0.008
GRIDSOIL	0.865**	0.056**
ZONESOIL	–0.095	–0.005
ERS1	0.066	0.003
ERS5	–0.286	–0.013
ERS7	–0.034	–0.002
ERS9	0.391	0.021
N	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%)	

[a]*PDA* equals one if the farmer adopted a personal digital assistant or handheld GPS device 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-likelihood unrestricted – log-likelihood restricted)
[e] 26 degrees of freedom at a 5% level of significance.