To the Graduate Council:

I am submitting herewith a thesis written by John Colby Torbett entitled "Perceived Importance of Precision Farming Technologies in Improving the Efficiency of Phosphorus, Potassium, and Nitrogen in Southeastern 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.

Roland K. Roberts, Major Professor

We have read this thesis
and recommend its acceptance:

Accepted for the council:

Vice Chancellor and
Dean of Graduate Studies

Perceived Importance of Precision Farming Technologies in Improving the Efficiency of Phosphorus, Potassium, and Nitrogen in Southeastern Cotton Production

A Thesis
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John Colby Torbett
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Dedication

This thesis is dedicated to the memory of my grandfather, Farrell J. Torbett, and the many generations of my family who have been involved in agriculture and is in honor of my parents, Phillip and Denise Torbett, my grandparents, Anna Jane Torbett and Jake and Mary Cross, and all other members of my family who have always supported me in everything that I have done.

Acknowledgements

I want to thank the many people who have helped make my experience at the University of Tennessee extremely rewarding. First I want to thank Dr. Roland Roberts for all of his time, effort, and patience. Thank you for always being available to answer my questions and for all of the many valuable suggestions. I would also like to thank the two other members of my graduate committee, Dr. Burton English and Dr. James Larson, for their time, support, and willingness to serve on my committee. I also wish to express my appreciation to my fellow graduate students; especially Bryan Combs, Jerrid Shannon, and Al Young, who were always there for support and entertainment.

I would also like to thank God for granting me the knowledge, patience, excellent graduate committee, and the support of both family and friends. God's support and guidance have helped me to be successful in all that I have done and continue to do. All of my fellow graduate students, friends, and family have given me the support that I have needed to sustain me through this process.

To everyone mentioned above, I will never forget your friendship and support.

Abstract

Understanding the factors that influence cotton farmers' perceptions about the importance of precision farming (PF) technologies in improving the efficiency of phosphorus (P), potassium (K), and nitrogen (N) fertilization is important because PF technologies have the potential to reduce costs, increase profit, and reduce negative environmental impacts. In the Southeastern United States, crops are generally produced in fields that have a high degree of variability in the availability of soil nutrients. The fertility level and amount removed by a crop at the end of the growing cycle are usually not uniform over an entire field. Because of high variability of nutrient levels in most agricultural fields, uniform applications of P, K, and N are likely to lead to excessive fertilization in some areas and inadequate fertilization in others.

Farmers in this study were already adopters of at least one PF technology, which allowed the analysis of the factors that influenced farmers' perceptions of the importance of those PF technologies they had adopted in using P, K, and N more efficiently. The objectives of this research were; 1) to determine the factors that influence PF technology adopters' perceptions about the importance of PF technologies in achieving more efficient P and K use and 2) to determine the factors that influence PF technology adopters' perceptions about the importance of PF technologies in achieving more efficient N use. To accomplish these objectives an ordered logit model was used to determine the factors influencing adopters' perceptions of PF technologies in using P, K, and N more efficiently. Marginal effects were also calculated for each variable.

The results indicate that, of the information gathering technologies, farmers who used remote sensing and mapping topography, slope, soil depth, etc. did not find the

information provided by these technologies useful in reducing P and K use. The results did show that farmers found management zone soil sampling, grid soil sampling, and on-the-go sensing more important in using P and K more efficiently. Of the farm and farmer characteristics, the results indicated that adopters over the age of 50 were more likely to have positive perceptions of PF technologies in using P and K more efficiently. Adopters who were using a computer for farm management were more likely to have positive perceptions of PF technologies in using P and K more efficiently. Adopters who rented a larger proportion of the land they farmed were more likely to have positive perceptions of PF technologies in more efficient P and K fertilization.

The results of the N equation indicate that, of the information gathering technologies, adopters who used mapping topography, slope, soil depth, etc. did not find the information provided by this technology to be useful in more efficient N fertilization. The results did show that farmers who used grid soil sampling, management zone soil sampling, yield monitoring without GPS, and on-the-go sensing found these technologies to be important in using N more efficiently. Farm and farmer characteristics show that adopters over the age of 50 using at least one PF technology were more likely to have positive perceptions of those PF technologies in using N more efficiently. Adopters in Georgia and Mississippi were more likely to have positive perceptions of the importance of PF technologies in increasing N efficiency than farmers located in Tennessee. Information from this study will be useful for farmers who are interested in using P, K, and N more efficiently to increase profits and/or reduce negative impacts to the environment.

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Part 1: Introduction

Understanding the factors that influence cotton farmers' perceptions about the importance of precision farming (PF) technologies in improving the efficiency of phosphorus (P), potassium (K), and nitrogen (N) fertilization is important because PF technologies have the potential to reduce costs and increase profit. In the Southern United States, crops are generally produced in fields that have a high degree of variability in the availability of soil nutrients. The fertility level and the amount of nutrients removed by a crop at the end of the growing cycle are usually not uniform over an entire field (Mallarino and Wittry). Because of high variability of nutrient levels in most agricultural fields, uniform applications of P, K, and N may lead to excessive fertilization in some areas and inadequate fertilization in others.

Yang, Everitt, and Bradford suggested that variable rate application of fertilizer could lead to less yield variability and higher fertilizer efficiency. Koch et al. found that variable rate application of N was more profitable than uniform N application, indicating a reduction in the amount of N applied and an increase in N efficiency. Variable rate application of P and K has also been shown to decrease the amount of P and K applied, reducing costs and increasing fertilizer efficiency (Wittry and Mallarino).

Negative impacts upon the environment due to over fertilization is an area of growing concern. Uniform rate application of fertilizer can result in a nutrient uptake as low as 30% of applied fertilizer. The remaining 70% has the potential to leach into groundwater or be lost as surface runoff (Legg and Meisinger). Lohr, Park, and Higley found that farmers may be willing to reduce input use to minimize negative environmental impacts, even if input reduction results in lower yields. Wang et al.

suggest switching from uniform rate application to variable rate application of fertilizer resulted in a reduction of surface runoff.

Precision farming information gathering technologies can provide a wealth of information about the spatial variability of a field. Farmers can use this information for variable-rate application of P, K, and N, leading to increased efficiency (Roberts et al., 2004). Cotton is a high-value, high input crop requiring extensive P, K, and N applications. English, Mahajanashetti, and Roberts suggested that variable rate application of fertilizer could lead to increased yields and/or lower fertilizer applications as opposed to uniform rate application. More efficient fertilizer applications can help reduce environmental impacts resulting from leaching and surface runoff (Wang et al.).

Several studies have found that a higher percentage of farmers have adopted variable rate application of P and K (Arnholt, Batte, and Prochaska; Batte and Arnholt; Daberkow, Fernandez-Cornejo, and Padgitt; Roberts et al., 2002; Roberts et al., 2004) and N (Batte and Arnholt; Daberkow, Fernandez-Cornejo, and Padgitt; Khanna, Epouhe, and Hornbaker; Roberts et al., 2002; Roberts et al., 2004) than other PF technologies. Discovering the factors affecting adopters' perceptions of PF technologies is important because of the potential for PF technologies to result in more efficient use of P, K, and N. Knowing these factors can be useful in targeting specific groups of farmers for the adoption and use of PF technologies to increase P, K, and N efficiency in meeting crop needs and reducing P, K, and N losses to the environment.

Research was available regarding farmers' perceptions of PF technologies. Several studies have analyzed the effects of farm and farmer characteristics on adoption of PF technologies (Adrian, Norwood, and Mask; Arnholt, Batte, and Prochaska; Batte and Arnholt; Daberkow, Fernandez-Cornejo, and Padgitt; Daberkow and McBride; Khanna; Khanna, Epouhe, and Hornbaker; Napier; Norton and Swinton; Plant; Popp and Griffin; Roberts, English, and Larson; Roberts et al., 2004; Roberts et al., 2002; Swinton and Lowenberg-DeBoer). While these studies dealt with adoption, the expected utility that farmers derive from the adoption and use of PF technologies is considered to be a factor affecting farmer decisions. Utility refers to overall satisfaction, which is influenced by a variety of factors, including psychological attitudes and personal experiences (Nicholson). Farmer utility therefore could be affected by their perceptions of PF technologies. These perceptions could influence their adoption decision.

Larkin et al. analyzed the factors that affected farmers' perceived environmental benefits from using PF technologies. They found that total acres planted had a positive affect on farmers' perceptions of an environmental benefit from using PF technologies. If the use of PF technologies was profitable, farmers were more likely to perceive improvements in environmental quality. Computer use increased the likelihood of farmers' perceiving improvements in environmental quality from the use of PF technologies. Farmers with higher crop yields perceived an improvement in environmental quality. In addition, farmers who felt that reducing input use was very important were more likely to have positive perceptions of PF technologies in improving environmental quality. Their study shows that farmers may have positive perceptions of PF even if they receive little monetary benefit from adoption of PF technologies.

Currently, more information is needed regarding the factors that affect farmers' perceptions of PF technologies in the more efficient use of P, K, and N. Farmers in this study were already adopters of at least one PF technology, which allowed the analysis of the factors that influenced farmers' perceptions of the importance of those PF technologies they had adopted in using P, K, and N more efficiently. The objectives of this research were: 1) to determine the factors that influence farmers' perceptions about the importance of PF technologies in achieving more efficient P and K use, and 2) to determine the factors that influence farmers' perceptions about the importance of PF technologies in achieving more efficient N use. Accomplishing these objectives will be useful for farmers who are interested in more efficient P, K, and N fertilization, which can lead to increased profits and/or reduced environmental impacts.

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Part 2: Perceived Importance of Precision Farming Technologies in Improving the Efficiency of Phosphorus and Potassium in Southeastern Cotton Production

Introduction

Understanding the factors that influence cotton farmers' perceptions about the importance of precision farming (PF) technologies in improving the efficiency of phosphorus (P) and potassium (K) fertilization is important because PF technologies have the potential to reduce costs, increase profit, and reduce negative environmental impacts. In the Southeastern United States, crops are generally produced in fields that have a high degree of variability in the availability of soil nutrients. The fertility level and the amount of nutrients removed by a crop at the end of the growing cycle are usually not uniform over an entire field (Mallarino and Wittry). Because of high variability of nutrient levels in most agricultural fields, uniform P and K applications may lead to excessive fertilization in some areas and inadequate fertilization in others.

Information provided by PF information gathering technologies can be used for variable rate application of P and K. Yang, Everitt, and Bradford found that variable rate application of fertilizer can increase yield, reduce spatial yield variability, and improve profits. Wittry and Mallarino suggested that variable rate application of P can increase crop yield and efficiency. Negative impacts upon the environment due to over-fertilization is another area of growing concern. Uniform rate application of fertilizer can result in a nutrient uptake as low as 30% of applied fertilizer. The remaining 70% has the potential to leach into groundwater or be lost as surface runoff (Legg and Meisinger). Lohr, Park, and Higley found that farmers may be willing to reduce input use to minimize environmental impacts, even if input reduction results in lower yields. Wang et al. suggest switching from uniform rate application to variable rate application of fertilizer resulted in a reduction of surface runoff.

Precision farming information gathering technologies can provide a wealth of information about the spatial variability of a field. Farmers can use this information for variable-rate application of P and K, leading to increased efficiency of P and K fertilization (Roberts et al., 2004). Cotton is a high-value, high-input crop requiring extensive P and K applications. English, Mahajanashetti, and Roberts suggested that variable rate application of fertilizer could lead to increased yields and/or lower fertilizer applications as opposed to uniform rate application. In addition, more efficient fertilizer applications can help reduce environmental impacts resulting from leaching and surface runoff (Wang et al.).

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Research was available regarding farmers' perceptions of PF technologies. Several studies have analyzed the effects of farm and farmer characteristics on adoption of PF technologies (Adrian, Norwood, and Mask; Arnholt, Batte, and Prochaska; Batte and Arnholt; Daberkow, Fernandez-Cornejo, and Padgitt; Daberkow and McBride; Khanna; Khanna, Epouhe, and Hornbaker; Napier; Norton and Swinton; Plant; Popp and Griffin; Roberts, English, and Larson; Roberts et al., 2004; Roberts et al., 2002; Swinton and Lowenberg-DeBoer). While these studies dealt with adoption, the expected utility that farmers derive from the adoption and use of PF technologies is considered to be a factor affecting farmer decisions. Utility refers to overall satisfaction, which is influenced by a variety of factors, including psychological attitudes and personal experiences (Nicholson). Farmer utility therefore could be affected by their perceptions of PF technologies. These perceptions could influence their adoption decision.

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Currently, more information is needed regarding the factors that affect farmers' perceptions of PF technologies in the more efficient use of P and K. Other studies have analyzed the factors affecting the adoption of PF technologies. Farmers in this study were already adopters of at least one PF technology, which allowed the analysis of the factors that influenced farmers' perceptions of the importance of those PF technologies they had adopted in using P and K more efficiently. The objective of this research was to determine the factors that influence farmers' perceptions about the importance of PF technologies in achieving more efficient P and K use. Accomplishing this objective will be useful for farmers who are interested in more efficient P and K fertilization, since efficient P and K use can lead to increased profits and/or decreased negative environmental impacts.

Data

Data were obtained from a survey by Roberts et al. (2002). Their survey was conducted in January and February of 2001 via mail. Following Dillman's general mail survey procedures, the questionnaire, a postage-paid return envelope, and a cover letter explaining the purpose of the survey were sent to cotton producers located in Alabama, Florida, Georgia, Mississippi, North Carolina, and Tennessee. The total number of surveys mailed was 6,423. Of the 6,423 questionnaires mailed, 196 were undeliverable and 251 indicated that they were not cotton farmers or they had retired. These responses were deleted from the number mailed to give 5,976 cotton producers who received the survey in the six-state region. A total of 1,131 cotton farmers responded by providing information about their adoption of PF technologies, giving a six-state response rate of 19%. Farmers were asked to indicate whether they had used the following site-specific information gathering technologies: grid soil sampling; management zone soil sampling; yield monitoring with GPS; yield monitoring without GPS; aerial photography; satellite imagery; plant tissue testing; on-the-go sensing; mapping topography, slope, soil depth, etc.; and soil survey maps. Farmers also were asked to indicate whether they had used variable-rate application technologies for the following inputs: nitrogen, P and K, lime, seed, growth regulator, defoliant, fungicide, herbicide, insecticide, and irrigation (Roberts et al., 2004).

Farmers who indicated they had used PF technologies were asked to rate the decision-making value of the PF technologies by indicating how important they thought the information was in reducing P and K use. While the efficient use of P and K could lead to increased applications of P and K on high yield-response areas of a field, low yield-response areas can receive substantially lower amounts of P and K with little reduction in yield, typically leading to an overall decrease in the field average P and K application rate (Roberts, English, and Mahajanashetti). Therefore farmers' rankings of the decision-making value of PF technologies in reducing P and K use was used as a proxy for P and K efficiency. Farmers could choose 5 rankings from 1 (not important) to 5 (very important). The number of PF technology adopters responding to this question was 204. This number was reduced to 144 because some farmers who responded to this question did not respond to other questions used in the analysis.

Methods

An ordered logit model was used to determine the factors that affect farmers' perceptions of the importance of PF technologies in improving the efficiency of P and K fertilization. Given the ordinal nature of the dependent variable, ordered logit or ordered probit analyses would be appropriate. An ordered logit model was used in the analysis because it is computationally less difficult than the ordered probit model. Differences between the ordered logit and ordered probit models are small and yield similar results (Greene). The ordered logit model was specified as:

1) $$y^* = \gamma' \mathbf{x} + \epsilon,$$

where y* is an unobserved value representing farmers' perceptions of the importance of PF technologies in improving the efficiency of P and K fertilization; **x** is the matrix of observed explanatory variables; γ is a parameter vector; and ϵ is a random error with a logistic distribution. What we observe from the survey data is:

2) $$\begin{aligned} y &= 0 \text{ if } y^* \leq \mu_0 \\ &= 1 \text{ if } \mu_0 < y^* \leq \mu_1 \\ &= 2 \text{ if } \mu_1 < y^* \leq \mu_2 \\ &= 3 \text{ if } \mu_2 < y^* \leq \mu_3 \\ &= 4 \text{ if } y^* > \mu_3 \end{aligned}$$

The μ's are unknown parameters to be estimated with γ. To estimate the parameters of this model, the dependent variable values must begin with 0 to allow for estimation of the intercept term (Dixon et al.). The μ's were calculated from estimates of $\gamma'\mathbf{x}$, where $-\gamma'\mathbf{x}$ is the threshold that divides the probability of a response being 0 from the probability of a response being 1, $\mu_1 - \gamma'\mathbf{x}$ is the threshold dividing the probabilities of a response being 1 or 2, and so on. This procedure provides estimates of the probabilities that an outcome will be 0, 1, 2, 3, or 4. Farmers have their own intensities of feeling, which depend on the explanatory variables, **x**, as well as unobservable factors ϵ.

The unknown parameters were estimated using LIMDEP (Greene). Marginal effects were calculated for each variable. The coefficients that were calculated from equation (1) are the effects of changes in the explanatory variables on the dependent variable. Because the relationship between the dependent and explanatory variables is nonlinear, the coefficients calculated from equation (1) determine the direction of the effect, not the magnitude (Greene; Sy et al.). Therefore, marginal effects were calculated to determine the effect of a change in an explanatory variable on the probability that the dependent variable will take on a certain value (Aradhyula and Tronstad). Each variable has five marginal effects, one for each ordinal category. The marginal effects for each ordinal category show the effect on the probability that y equaled 0, 1, 2, 3, or 4. The marginal effects of continuous variables were calculated by differentiating the probabilities with respect to the explanatory variables (Larkin et al.; Roberts et al., 2004). The marginal effects of dummy variables were computed as $\Pr[y \mid x = 1] - \Pr[y \mid x = 0]$, where y represents the importance that farmers placed on PF technologies in improving P and K efficiency, from not important (0) to very important (4), and x is the dummy variable being considered (Greene). A likelihood ratio chi-squared test statistic was used to test the joint significance of the explanatory variables (SAS Institute). Multicollinearity diagnostics were also performed (Belsley, Kuh, and Welsch).

Empirical Model for P and K

To conform with the format of the logit model, responses to the P and K question (PK) were recoded to 0 through 4, which correspond directly with the farmers' original ratings between 1 and 5. The data had eight responses with PK = 0, 11 responses with PK = 1, 37 responses with PK = 2, 56 responses with PK = 3, and 32 responses with PK = 4 (Roberts et al., 2002). Variable means and definitions are presented in Table 1, which is located in the appendix. The ordered logit model was specified as:

4) $$PK_i = \gamma_0 + \gamma_1 YMGPS_i + \gamma_2 YMNOGPS_i + \gamma_3 REMOTE_i + \gamma_4 MAP_i + \gamma_5 SOILM_i + \gamma_6 SOILG_i + \gamma_7 ONTHEGO_i + \gamma_8 TISSUE_i + \gamma_9 SOILSUR_i +$$

$\gamma_{10}FARMSIZE_i + \gamma_{11}OWNRENT_i + \gamma_{12}YIELD_i + \gamma_{13}COLLEGE_i +$

$\gamma_{14}OVER50_i + \gamma_{15}COMPUTER_i + \gamma_{16}PROFITABLE_i +$

$\gamma_{17}IMPORTANCE_i + \gamma_{18}AL_i + \gamma_{19}FL_i + \gamma_{20}GA_i + \gamma_{21}MS_i + \gamma_{22}NC_i + \epsilon_i,$

where YMGPS = 1 if the farmer used yield monitoring with GPS, and 0 otherwise; YMNOGPS = 1 if the farmer used yield monitoring without GPS, and 0 otherwise; REMOTE = 1 if the farmer used remote sensing, either aerial photos or satellite images, and 0 otherwise; MAP = 1 if the farmer used mapping topography, slope, soil depth, etc., and 0 otherwise; SOILM = 1 if the farmer used management zone soil sampling, and 0 otherwise; SOILG = 1 if the farmer used grid soil sampling, and 0 otherwise; ONTHEGO = 1 if the farmer used on-the-go sensing, and 0 otherwise; TISSUE = 1 if the farmer used plant tissue testing, and 0 otherwise; SOILSUR = 1 if the farmer used soil survey maps, and 0 otherwise; FARMSIZE is the total number of acres planted by the farmer (1000 acres); OWNRENT is a ratio of the number of acres owned divided by the total number of acres planted; YIELD is the farm-average cotton lint yield (1,000 lb); COLLEGE = 1 if the farmer attended college, and 0 otherwise; OVER50 = 1 if the farmer is over 50 years of age, and 0 otherwise; COMPUTER = 1 if the farmer used a computer for farm management, and 0 otherwise; PROFITABLE = 1 if the farmer thought precision farming was profitable on their fields, and 0 otherwise; IMPORTANCE is an ordinal rating of how important the farmer thought precision farming would be in five years for cotton, corn, peanuts, rice soybeans, tobacco, and wheat, ranging from unimportant (1) to very important (5) for each crop. The farmer's importance rating for a crop was weighted by the number of acres of that crop, giving a weighted average importance rating for the farmer ranging from unimportant (1) to very important (5) (the sum of the crop weights equaled one); AL = 1 if the farm was located in Alabama, and 0 otherwise; FL = 1 if the farm was located in Florida, and 0 otherwise; GA = 1 if the farm was located in Georgia, and 0 otherwise; MS = 1 if the farm was located in Mississippi, and 0 otherwise; and NC = 1 if the farm was located in North Carolina, and 0 otherwise. The location variable for Tennessee was excluded and was reflected in the intercept. γ_0 through γ_{22} are parameters to be estimated; ϵ is an error term with a logistic distribution; and i is a subscript representing the ith farmer.

Yield monitoring is used to determine the yield of a crop at different locations within a field (Plant). When used in conjunction with a GPS receiver (YMGPS), the yield of specific areas in the field can be mapped, differentiating the areas of a field that are more productive from those that are less productive (Pierce et al.). Once less productive areas of a field are identified, the farmer can attempt to determine the cause of the low yields. Thus, the spatial variability discovered from yield monitoring can help a farmer to identify areas of a field that may have P and K deficiencies or where P and K need not be applied. Farmers using yield monitors with or without GPS were expected to rank higher the importance of PF technologies in improving the efficiency of P and K, therefore the signs for γ_1 and γ_2 were expected to be positive. Even without GPS (YMNOGPS), yield monitoring can improve a farmer's knowledge of a field and help in making decisions about P and K applications.

Remote sensing (REMOTE) can be used to identify soil properties, monitor plant growth and development, and detect environmental stresses, which may limit crop productivity (Dobermann et al.). Remote sensing may be important for discovering spatial variability of P and K. Bare soil brightness often reveals variability in P concentrations (Varvel et al.). Soil chemical properties, such as P content, are almost always positively correlated with organic matter content, which can be determined through the use of remote sensing (Schepers, Schlemmer, and Ferguson). Remote sensing is able to show the variation in P and K before and during the growth and development of a crop. Lower yields caused by P and K deficiencies can be identified from remotely sensed images. As a result of the potential benefits from using remote sensing in improving the efficiency of P and K use, the sign for γ_3 was expected to be positive.

Mapping topography (MAP) is useful in determining the effect that topographical features have on the spatial variability of P and K. Landscape topography affects soil physical and chemical properties by erosion and deposition processes (Iqbal et al.). Topography affects soil properties, with soil properties varying on slopes and in low lying areas. P and K may also be removed from slopes through tillage and the process of erosion. Farmers can use topographical maps to help in identifying the cause of reduced yield or areas of a field that may need more intense management of P and K. Therefore, the sign for γ_4 was expected to be positive.

Precision soil sampling improves the analysis of field soil properties by determining the spatial variation of the measured properties within the field (Rains, Thomas, and Vellidis). Grid soil sampling (SOILG) involves the development of a uniform grid over the field and sampling within each grid. The other precision soil sampling technique uses historical data, yield maps, aerial photos, and a farmer's general knowledge of field variation to divide the field into management zones (SOILM) with different yield response potentials. Each management zone is treated as an area with homogeneous properties (Rains, Thomas, and Vellidis). Management zone soil sampling draws soil samples from each zone. Precision soil sampling provides information about the spatial variability of P and K within a field. As a result, farmers can apply P and K at varying rates throughout the field according to crop needs, increasing the efficiency of P and K fertilization. Farmers who used grid or management soil sampling were expected to rank the importance of PF technologies in improving the efficiency of P and K fertilization higher. Therefore, the signs for γ_5 and γ_6 were expected to be positive.

On-the-go sensing (ONTHEGO) can be used to determine spatial variability in P and K throughout a field. Adamchuk et al. analyzed different on-the-go sensing technologies, many of which were useful in identifying fertilizer deficiencies. On-the-go sensing for P and K can be of great benefit to farmers. Grid soil sampling costs are expensive. Using on-the-go sensors to measure P and K concentrations could reduce the costs of soil sampling and result in a higher density of sample measurements. Farmers using on-the-go sensing were expected to rank the importance of PF technologies in improving the efficiency of P and K fertilization higher, resulting in γ_7 being positive.

Plant notes the importance of plant tissue samples (TISSUE) in determining if plant fertilizer needs are being met. Bell et al. analyzed tissue sampling to determine if cotton fertilizer needs were being met. They found that tissue sampling was useful in identifying fertilizer deficiencies in cotton. Tissue testing can help farmers identify whether fertilizer deficiency is the cause of low yield in one or more areas of a field. Random samples can also be taken to determine if crop fertilizer needs are being met. These samples can be collected from uniform grids or from management zones within a field. Farmers using plant tissue testing to gather spatial information were expected to rank higher the importance of PF technologies in improving the efficiency of P and K fertilization. Thus the sign for γ_8 was expected to be positive.

A review of literature helped identify potential farm and farmer characteristics influencing technology perceptions and hypotheses about their influence on how important cotton farmers would perceive PF technologies in the more efficient use of P and K. Farm size (FARMSIZE) was expected to positively affect adopters' perceptions of the importance of PF technologies in using P and K more efficiently ($\gamma_{10} > 0$). Larger farm size has been associated with higher adoption rates for certain crops (Cowan). Farmers with more acreage and fields have greater opportunities to observe spatial variability in soil P and K (Larkin), and are more likely to benefit from greater efficiency in the application of P and K through the use of PF technologies than other farmers. The ratio of the number of acres owned divided by the total number of acres farmed (OWNRENT) was expected to have a negative effect on adopter perceptions ($\gamma_{11} < 0$), meaning that adopters who own a larger proportion of the land that they farm are expected to have lower perceptions of PF technologies in using P and K more efficiently than those who rent a larger proportion of their land. Adopters who rent a larger proportion of their land may have limited knowledge of the soil characteristics on rented land. Adopters may experience a large increase in knowledge about P and K spatial variability on rented land from the use of PF information gathering technologies. The knowledge gained about P and K spatial variability can be used for variable rate application of P and K, which can lead to increased P and K efficiency. This increase in efficiency would likely have a positive impact on adopters' perceptions of the importance of information provided by PF technologies in using P and K more efficiently on rented land. Yield (YIELD) was expected to have a positive influence on adopters' perceptions of PF technologies ($\gamma_{12} > 0$). Higher average land quality may indicate greater opportunities for spatial yield response variability, thus having a positive impact upon perceptions.

Because the use of PF technologies requires considerable analytical abilities, adopters who have attended college (COLLEGE) may have higher perceptions of the importance of PF technologies in the more efficient use of P and K because they are more able to recognize and reap the benefits of PF technologies, leading to the perception of greater importance of PF technologies in improving the efficiency of P and K fertilization ($\gamma_{13} > 0$). Older farmers typically have shorter planning horizons, are resistant to change, and have less exposure to the technologies required for PF (Roberts et al., 2004). These characteristics suggest that older farmers are more risk averse (Dimara and Skuras), which would have a negative impact on farmers' perceptions of PF technologies in increasing P and K efficiency. In this study, older farmers with shorter planning horizons were already adopters of PF technologies, suggesting that they may have been less risk averse than older farmers in general. Older adopters have also been farming longer than younger adopters, providing them more experience in recognizing improvements in P and K efficiency from the use of PF technologies and thus they may have higher perceptions of their importance. Therefore, the sign of OVER50 could not be determined *a priori* ($\gamma_{14} <=> 0$). Computer use for farm management (COMPUTER) was expected to have a positive influence on the perception of PF technologies in the more efficient use of P and K because computers are integral components in the use of PF technologies ($\gamma_{15} > 0$).

The perceived profitability (PROFITABLE) of PF was expected to affect adopters' perceptions of PF technologies. Higher profits could result because of increased yields and/or lower costs from the use of PF technologies in applying P and K more efficiently. Higher profits resulting from more efficient P and K use would likely lead to an increase in farmer utility. This increase in utility could result in farmers having higher perceptions of the importance of PF technologies in using P and K more efficiently. Therefore, perceived profitability was expected to have a positive influence on the perception of PF technologies in the more efficient use of P and K ($\gamma_{16} > 0$). Adopters who felt that precision farming of cotton, corn, peanuts, rice, soybeans, tobacco, and wheat would be important in five years (IMPORTANCE) were expected to have higher perceptions of the how importance of PF technologies in the more efficient use of P and K ($\gamma_{17} > 0$). Adopters who are more optimistic about the future of PF technologies may have a higher utility for PF technologies, increasing their perceptions of PF technologies in efficient P and K fertilization. Location variables AL, FL, GA, MS and NC were included to test whether farmers using PF technologies in Alabama, Florida, Georgia, Mississippi, and North Carolina had higher or lower probabilities of having positive perceptions of PF technologies in the more efficient use of P and K relative to farmers in Tennessee (Larkin et al.; Roberts et al., 2004). The expected signs for γ_{18} through γ_{22} were not specified. The survey data were allowed to identify location differences that were present.

Results

Results from estimating equation (4) are reported in Tables 2 and 3, which are located in the appendix. The Chi-squared statistic of 36.68 (Table 3) was significant at the $\alpha = 0.05$ level, indicating rejection of the null hypothesis that all regressors in the model are zero. Multicollinearity diagnostics revealed that multicollinearity was not a problem (Belsley, Kuh, and Welsch). The model correctly predicted 42.3% of the responses.

Most of the information gathering technologies were statistically significant at the $\alpha = 0.10$ level. The coefficients and marginal effects for the information gathering technology variables are reported in table 2. Three statistically significant variables had their hypothesized signs (SOILM, SOILG, ONTHEGO). The coefficients for both management zone soil sampling (SOILM) and grid soil sampling (SOILG) were positive, suggesting that farmers who used precision soil sampling perceived greater importance of PF technologies in improving the efficiency of P and K use than those who did not use precision soil sampling. The negative marginal effects representing the probabilities that y would equal 0 or 1 indicate that farmers who were using management zone soil sampling had a lower probability of falling into the lower ordinal categories. The positive marginal effect showing the probability that y would equal 4 suggests that farmers who were using management zone soil sampling had a higher probability of falling into the highest ordinal category. The negative effects for the lower ordinal categories and the positive effect for the highest ordinal category for management zone soil sampling indicate a rightward shift in the probability distribution. The effect is an unambiguous shift of some probability out of the lower ordinal categories and more probability into the highest ordinal category, with the effect of the middle category (y = 2) being ambiguous. The marginal effects for grid soil sampling also show that farmers are less likely to fall into ordinal categories 0 and 1 and are more likely to fall into ordinal category 4, with the effect of the middle category being ambiguous. The positive coefficient for ONTHEGO suggests that farmers who used on-the-go sensing found it important in using P and K more efficiently. The marginal effects show that farmers who were using on-the-go sensing were highly likely to rate the decision-making value of PF technologies in using P and K more efficiently as very important.

Two statistically significant coefficients had signs opposite of those hypothesized. The sign of the negative coefficients for MAP and REMOTE suggest that farmers did not find mapping topography, slope, soil depth, etc. or remote sensing important in the more efficient use of P and K. Marginal effects for both of these coefficients show that farmers who were using these technologies were more likely to have lower perceptions of the importance of PF technologies in using P and K more efficiently. The coefficients for yield monitoring with GPS (YMGPS) and without GPS (YMNOGPS), plant tissue testing (TISSUE), and soil survey maps (SOILSUR) were insignificant in the model. This finding suggests that each of these variables had neither a positive nor a negative effect on farmers' perceptions of PF technologies in using P and K more efficiently.

The coefficients and marginal effects for the farm and farmer characteristics variables are reported in Table 3. Three of these variables were significant, with one having its hypothesized sign. The coefficient for COMPUTER was positive as hypothesized, suggesting that adopters using a computer for farm management were more likely to have a higher perception of the importance of PF technologies in using P and K more efficiently. The marginal effects show that adopters who were using computers for farm management were more likely to fall into the higher ordinal category.

The coefficient for OWNRENT was negative as hypothesized, suggesting that adopters who owned a larger portion of the land they farmed were less likely to have higher perceptions of PF technologies in efficient P and K fertilization. This finding suggests that PF technology adopters who are renting a larger proportion of their land found PF technologies to be useful in increasing the knowledge of P and K spatial variability on rented land. The knowledge gained from the information gathering technologies about spatial variability in P and K concentrations on rented land can be used to variable rate apply P and K, leading to more efficient P and K fertilization.

Farmer age (OVER50) had a positive sign, suggesting that adopters over the age of 50 found PF technologies to be more important in the efficient use of P and K. Marginal effects for OVER50 show that as age increases, adopters are more likely to have higher perceptions of PF technologies in using P and K efficiently. Older adopters have been farming longer than younger adopters. The positive coefficient for OVER50 suggests because older adopters have more experience farming, they may be able to recognize an improvement in the efficiency of P and K use from the use of PF technologies, thus increasing their perceptions of the importance of the PF technologies in more efficient P and K fertilization. FARMSIZE, YIELD, COLLEGE, PROFITABLE, IMPORTANCE, and farm location did not significantly affect an adopter's perception of the importance of PF technologies in using P and K more efficiently.

Summary and Conclusions

Farmers who had adopted PF technologies were asked to rate the decision-making value of the technologies that they had used by indicating from 1 (not important) to 5 (very important) how important they felt the information from using these technologies was in reducing P and K use. Sixty one percent of adopters responded with an answer of 4 or 5, meaning that these adopters found the information provided by PF technologies to be important in using P and K more efficiently.

The results from the ordered logit model suggest differences in the probability of adopters' having higher perceptions of PF technologies in using P and K more efficiently. Of the information gathering technologies, adopters who used remote sensing and mapping topography, slope, soil depth, etc. did not find the information provided by these technologies useful in more efficient P and K fertilization. The results did show that adopters found management zone soil sampling, grid soil sampling, and on-the-go sensing more important in using P and K more efficiently. These results indicate that farmers would benefit the most from using management zone soil sampling, grid soil sampling, and on-the-go sensing to gather information about P and K spatial variability. This information can then be used to apply P and K more efficiently, which could improve profits and minimize environmental impacts.

Because younger farmers are typically less risk averse than older farmers, they may be more likely to adopt PF technologies than older farmers. The results of this research indicate that older farmers who had already adopted at least one PF technology were more likely to have positive perceptions of those PF technologies in using P and K more efficiently. This finding suggests that farmers over the age of 50 are more likely to perceive an increase in P and K efficiency from the use of PF technologies, which suggests that farmers over the age of 50 should be encouraged to use PF technologies to increase P and K efficiency, leading to increased profit and fewer negative environmental impacts.

Adopters using at least one PF technology and who used a computer for farm management were more likely to have positive perceptions of PF technologies in efficient P and K fertilization. This suggests that adopters using a computer for farm management may be able to observe greater changes in P and K efficiency than adopters who do not use a computer for farm management. Adopters who rent a larger proportion of the land that they farm were more likely to have positive perceptions of PF technologies in using P and K more efficiently. This finding suggests that PF technology adopters who are renting a larger proportion of their land found PF technologies to be useful in increasing the knowledge of P and K spatial variability on rented land, leading to more efficient P and K use.

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Appendix

Table 1. Definitions of Variables and Means for P and K Model

	Mean	Definition
Dependent Variable		
PK	2.65	Farmer rating of how important the information provided by PF technologies was in reducing P and K use (not important = 0; very important = 4)
Explanatory Variables		
Information gathering technologies		
YMGPS	0.25	Used yield monitoring with GPS (yes = 1; no = 0)
YMNOGPS	0.24	Used yield monitoring without GPS (yes = 1; no = 0)
REMOTE	0.10	Used satellite images and/or aerial photos (yes = 1; no = 0)
MAP	0.08	Used mapping topography, slope, soil depth, etc. (yes = 1;
SOILM	0.42	Used management zone soil sampling (yes = 1; no = 0)
SOILG	0.60	Used grid soil sampling (yes = 1; no = 0)
ONTHEGO	0.02	Used on-the-go sensing (yes = 1; no = 0)
TISSUE	0.38	Used plant tissue testing (yes = 1; no = 0)
SOILSUR	0.39	Used soil survey maps (yes = 1; no = 0)

Table 1 Continued

	Mean	Definition
Farm and farmer characteristics		
FARMSIZE	2.40	Total acres planted (1,000 acres)
OWNRENT	0.39	Acres owned divided by total acres planted
YIELD	0.70	Farm average cotton lint yield (1,000 lb)
COLLEGE	0.79	Attended at least one year of college (yes = 1; no = 0)
OVER50	0.30	Age of farmer greater than 50 (years) (yes = 1; no = 0)
COMPUTER	0.79	Used a computer for farm management (yes = 1; no = 0)
PROFITABLE	0.60	Farmer thought that PF was profitable on their fields (yes = 1; no = 0)
IMPORTANCE	3.89	Farmer thought that PF would be unimportant (1) to very important (5) in his/her state in
Farm location		
AL	0.22	Farm located in Alabama (yes = 1; no = 0)
FL	0.03	Farm located in Florida (yes = 1; no = 0)
GA	0.17	Farm located in Georgia (yes = 1; no =)
MS	0.22	Farm located in Mississippi (yes = 1; no = 0)
NC	0.26	Farm located in North Carolina (yes = 1; no = 0)

Table 2. P and K Model Ordered Logit Estimates and Marginal Effects for Information Gathering Technologies

Variable	Coefficient[a]	Marginal Effects for Ordinal Categories				
		y = 0	y = 1	y = 2	y = 3	y = 4
CONSTANT	-2.177*	N/A[b]	N/A	N/A	N/A	N/A
YMGPS	0.525	-0.017	-0.026	-0.076	0.035	0.084
YMNOGPS	0.493	-0.016	-0.024	-0.072	0.033	0.079
REMOTE	-1.372**	0.085	0.102	0.143	-0.190	-0.140
MAP	-1.586**	0.110	0.123	0.141	-0.225	-0.149
SOILM	0.887**	-0.031	-0.045	-0.126	0.066	0.136
SOILG	0.990**	-0.040	-0.057	-0.136	0.097	0.137
ONTHEGO	1.908*	-0.033	-0.053	-0.216	-0.110	0.412
TISSUE	-0.085	0.003	0.005	0.012	-0.008	-0.012
SOILSUR	-0.233	0.009	0.013	0.034	-0.021	-0.034
n	144					
χ^2 22 df	36.68***					

[a] ***, **, and * indicate statistical significance at the $\alpha = 0.10$, $\alpha = 0.05$, and $\alpha = 0.01$ levels, respectively.

[b] N/A indicates that the value is not applicable

Table 3. P and K Model Ordered Logit Estimates and Marginal Effects for Farm and Farmer Characteristics

		Marginal Effects for Ordinal Categories				
Variable	Coefficient[a]	y = 0	y = 1	y = 2	y = 3	y = 4
FARMSIZE	-0.025	0.001	0.001	0.004	-0.002	-0.004
OWNRENT	-1.255**	0.045	0.067	0.183	-0.111	-0.184
YIELD	-0.362	0.013	0.019	0.053	-0.032	-0.053
COLLEGE	-0.512	0.016	0.025	0.074	-0.033	-0.082
OVER50	1.295***	-0.038	-0.058	-0.178	0.054	0.222
COMPUTER	0.631*	-0.026	-0.037	-0.089	0.065	0.086
PROFITABLE	0.300	-0.011	-0.016	-0.043	0.028	0.043
IMPORTANCE	0.154	-0.006	-0.008	-0.022	0.014	0.023
AL	-0.451	0.018	0.026	0.064	-0.048	-0.061
FL	-0.618	0.029	0.040	0.082	-0.077	-0.075
GA	0.163	-0.006	-0.008	-0.024	0.013	0.025
MS	-0.132	0.005	0.007	0.019	-0.012	-0.019
NC	-0.300	0.115	0.017	0.043	-0.029	-0.042
$\mu 1$	1.046***					
$\mu 2$	2.755***					
$\mu 3$	4.779***					

[a] ***, **, and * indicate statistical significance at the $\alpha = 0.01$, $\alpha = 0.05$, and $\alpha = 0.10$ levels, respectively.

Part 3: Perceived Importance of Precision Farming Technologies in Improving the Efficiency of Nitrogen in Southeastern Cotton Production

Introduction

Understanding the factors that influence cotton farmers' perceptions about the importance of precision farming (PF) technologies in improving the efficiency of nitrogen (N) fertilization is important because PF technologies have the potential to reduce costs, increase profit, and reduce negative environmental impacts. In the Southeastern United States, crops are generally produced in fields that have a high degree of variability in the availability of soil nutrients. The fertility level and amount removed by a crop at the end of the growing cycle are usually not uniform over an entire field (Mallarino and Wittry). Because of high variability of nutrient levels in most agricultural fields, uniform N applications are likely to lead to excessive fertilization in some areas and inadequate fertilization in others.

Yang, Everitt, and Bradford suggested that variable rate application of fertilizer could lead to less yield variability and higher fertilizer efficiency, thus higher profits. Koch et al. found that variable rate application of N was more profitable than uniform N application, indicating a reduction in the amount of N applied and an increase in N efficiency. Negative impacts upon the environment due to over-fertilization is another area of growing concern. Uniform rate application of fertilizer can result in a nutrient uptake as low as 30% of applied fertilizer. The remaining 70% has the potential to leach into groundwater or be lost as surface runoff (Legg and Meisinger). Lohr, Park, and Higley found that farmers may be willing to reduce input use to minimize environmental impacts, even if input reduction results in lower yields. Wang et al. suggest switching from uniform rate application to variable rate application of fertilizer resulted in a reduction of surface runoff.

Precision farming information gathering technologies can provide a wealth of information about the spatial variability of a field. Farmers can then take this information and use variable-rate application of N, leading to increased efficiency of N fertilization (Roberts et al., 2004). Cotton is a high value crop, requiring extensive input applications. English, Mahajanashetti, and Roberts suggested that variable rate application of fertilizer could lead to increased yields and/or lower fertilizer applications as opposed to uniform rate application. In addition, more efficient fertilizer applications can help reduce environmental impacts resulting from leaching and surface runoff (Wang et al.).

Several studies have found that a higher percentage of farmers have adopted variable rate application of N than other PF technologies (Batte and Arnholt; Daberkow, Fernandez-Cornejo, and Padgitt; Khanna, Epouhe, and Hornbaker; Roberts et al., 2002; Roberts et al., 2004). Discovering the factors affecting adopters' perceptions of PF technologies is important because of the potential for PF technologies to result in more efficient use of N. Knowing these factors can be useful in targeting specific groups of farmers for the adoption and use of PF technologies to increase N efficiency in meeting crop needs and reducing N losses to the environment.

Research was available regarding farmers' perceptions of PF technologies. Several studies have analyzed the effects of farm and farmer characteristics on adoption of PF technologies (Adrian, Norwood, and Mask; Arnholt, Batte, and Prochaska; Batte and Arnholt; Daberkow, Fernandez-Cornejo, and Padgitt; Daberkow and McBride; Fernandez-Cornejo, Daberkow, and McBride; Griffin et al.; Khanna; Khanna, Epouhe, and Hornbaker; McBride and Daberkow; Napier, Robinson, and Tucker; Norton and Swinton; Plant; Popp and Griffin; Roberts, English, and Larson; Roberts et al., 2004;

Roberts et al., 2002; Swinton and Lowenberg-DeBoer). While these studies dealt with adoption, the expected utility that farmers derive from the adoption and use of PF technologies is considered to be a factor affecting farmer decisions. Utility refers to overall satisfaction, which is influenced by a variety of factors, including psychological attitudes and personal experiences (Nicholson). Farmer utility therefore could be affected by their perceptions of PF technologies. These perceptions could influence their adoption decision.

Larkin et al. analyzed the factors that affected farmers' perceived environmental benefits from using PF technologies. They found that total acres planted had a positive affect on farmers' perceptions of an environmental benefit from using PF technologies. If the use of PF technologies was perceived to be profitable, farmers were more likely to perceive improvements in environmental quality. Computer use increased the likelihood of farmers' perceiving improvements in environmental quality from the use of PF technologies. Farmers with higher crop yields perceived an improvement in environmental quality. In addition, farmers who felt that reducing input use was very important were more likely to have positive perceptions of PF technologies in improving environmental quality. Their study shows that farmers may have positive perceptions of PF even if they receive little monetary benefit from adoption of PF technologies.

Currently, more information is needed regarding the factors that affect farmers' perceptions of PF technologies in the more efficient use of N. Other studies have analyzed the factors affecting the adoption of PF technologies. Farmers in this study were already adopters of at least one PF technology, which allowed the analysis of factors that influenced farmers' perceptions of the importance of those PF technologies they had adopted in using N more efficiently. The objective of this research was to determine the factors that influence farmers' perceptions about the importance of PF technologies in achieving more efficient N use. Accomplishing this objective will be useful for farmers who are interested in more efficient N fertilization, since efficient N use can lead to increased profits and/or decreased environmental impacts.

Data

Data for this research was obtained from a survey by Roberts et al. (2002). Their survey was conducted in January and February of 2001 via mail. Following Dillman's general mail survey procedures, the questionnaire, a postage-paid return envelope, and a cover letter explaining the purpose of the survey were sent to cotton producers located in Alabama, Florida, Georgia, Mississippi, North Carolina, and Tennessee. The total number of surveys mailed was 6,423. Of the 6,423 questionnaires mailed, 196 were undeliverable and 251 indicated that they were not cotton farmers or they had retired. These responses were deleted from the number mailed to give 5,976 cotton producers who received the survey in the six-state region. A total of 1,131 cotton farmers responded by providing information about their adoption of PF technologies, giving a six-state response rate of 19%. Farmers were asked to indicate whether they had used the following site-specific information gathering technologies: grid soil sampling; management zone soil sampling; yield monitoring with GPS; yield monitoring without GPS; aerial photography; satellite imagery; plant tissue testing; on-the-go sensing; mapping topography, slope, soil depth, etc.; and soil survey maps. Farmers also were asked to indicate whether they had used variable-rate application technologies for the following inputs: nitrogen, P and K, lime, seed, growth regulator, defoliant, fungicide, herbicide, insecticide, and irrigation (Roberts et al., 2004).

Farmers who indicated they had used PF technologies were asked to rate the decision-making value of the PF technologies by indicating how important they thought the information was in reducing N use. While the efficient use of N could lead to increased applications of N on high yield-response areas of a field, low yield-response areas can receive substantially lower amounts of N with little reduction in yield, typically leading to an overall decrease in the field average N application rate (Roberts, English, and Mahajanashetti). Therefore farmers' rankings of the decision-making value of PF technologies in reducing N use was used as a proxy for N efficiency. Farmers could choose 5 rankings from 1 (not important) to 5 (very important). The number of PF technology adopters responding to this question was 194. This number was reduced to 135 because some farmers who responded to this question did not respond to other questions used in the analysis.

Methods

An ordered logit model was used to determine the factors that affect farmers' perceptions of the importance of PF technologies in improving the efficiency of N fertilization. Given the ordinal nature of the dependent variable, ordered logit or ordered probit analyses would be appropriate. An ordered logit model was used in the analysis because it is computationally less difficult than the ordered probit model. Differences between the ordered logit and ordered probit models are small and yield similar results (Greene). The ordered logit model was specified as:

1) $$y^* = \beta'\mathbf{x} + \epsilon,$$

where y* is an unobserved value representing farmers' perceptions of the importance of PF technologies in improving the efficiency of N fertilization; **x** is the matrix of observed explanatory variables; β is a parameter vector; and ϵ is a random error with a logistic distribution. What we observe from the survey data is:

2) $$\begin{aligned} y &= 0 \text{ if } y^* \leq \mu_0 \\ &= 1 \text{ if } \mu_0 < y^* \leq \mu_1 \\ &= 2 \text{ if } \mu_1 < y^* \leq \mu_2 \\ &= 3 \text{ if } \mu_2 < y^* \leq \mu_3 \\ &= 4 \text{ if } y^* > \mu_3 \end{aligned}$$

The μ's are unknown parameters to be estimated with β. To estimate the parameters of this model, the dependent variable values must begin with 0 to allow for estimation of the intercept term (Dixon et al.). The μ's were calculated from estimates of $\beta'\mathbf{x}$, where $-\beta'\mathbf{x}$ is the threshold that divides the probability of a response being 0 from the probability of a response being 1, $\mu_1 - \beta'\mathbf{x}$ is the threshold dividing the probabilities of a response being 1 or 2, and so on. This procedure provides estimates of the probabilities that an outcome will be 0, 1, 2, 3, or 4. Farmers have their own intensities of feeling, which depend on the explanatory variables, **x**, as well as unobservable factors ϵ.

The unknown parameters were estimated using LIMDEP (Greene). Marginal effects were calculated for each variable. The coefficients that were calculated from equation (1) are the effects of changes in the explanatory variables on the dependent variable. Because the relationship between the dependent and explanatory variables is nonlinear, the coefficients calculated from equation (1) determine the direction of the effect, not the magnitude (Greene; Sy et al.). Marginal effects were calculated to determine the effect of a change in an explanatory variable on the probability that the dependent variable will take on a certain value (Aradhyula and Tronstad). Each variable has five marginal effects, one for each ordinal category. The marginal effects for each ordinal category show the effect on the probability that y equaled 0, 1, 2, 3, or 4. The marginal effects of continuous variables were calculated by differentiating the probabilities with respect to the explanatory variables (Larkin et al.; Roberts et al., 2004). The marginal effects of dummy variables were computed as $Pr[y \mid x = 1] - Pr[y \mid x = 0]$, where y represents the importance that farmers placed on PF technologies in improving N efficiency, from not important (0) to very important (4), and x is the dummy variable being considered (Greene). A likelihood ratio chi-squared test statistic was used to test the joint significance of the explanatory variables (SAS Institute). Multicollinearity diagnostics were also performed (Belsley, Kuh, and Welsch).

Empirical Model for N

To conform with the format of the logit model, responses to the N question (N) were recoded to 0 through 4, which correspond directly with the farmers' original ratings between 1 and 5. The data had 10 responses with N = 0, nine responses with N = 1, 33 responses with N = 2, 50 responses with N = 3, and 33 responses with N = 4 (Roberts et al., 2002). Variable definitions and means are presented in Table 1 (Appendix). The ordered logit model was specified as:

4) $$N_i = \beta_0 + \beta_1 YMGPS_i + \beta_2 YMNOGPS_i + \beta_3 REMOTE_i + \beta_4 MAP_i + \beta_5 SOILM_i + \beta_6 SOILG_i + \beta_7 ONTHEGO_i + \beta_8 TISSUE_i + \beta_9 SOILSUR_i +$$

$\beta_{10}FARMSIZE_i + \beta_{11}OWNRENT_i + \beta_{12}YIELD_i + \beta_{13}COLLEGE_i + \beta_{14}OVER50_i + \beta_{15}COMPUTER_i + \beta_{16}PROFITABLE_i + \beta_{17}IMPORTANCE_i + \ + \beta_{18}AL_i + \beta_{19}FL_i + \beta_{20}GA_i + \beta_{21}MS_i + \beta_{22}NC_i + \epsilon_i,$

where YMGPS = 1 if the farmer used yield monitoring with GPS, and 0 otherwise; YMNOGPS = 1 if the farmer used yield monitoring without GPS, and 0 otherwise; REMOTE = 1 if the farmer used remote sensing, either aerial photos or satellite images, and 0 otherwise; MAP = 1 if the farmer used mapping topography, slope, soil depth, etc., and 0 otherwise; SOILM = 1 if the farmer used management zone soil sampling, and 0 otherwise; SOILG = 1 if the farmer used grid soil sampling, and 0 otherwise; ONTHEGO = 1 if the farmer used on-the-go sensing, and 0 otherwise; TISSUE = 1 if the farmer used plant tissue testing, and 0 otherwise; SOILSUR = 1 if the farmer used soil survey maps, and 0 otherwise; FARMSIZE is the total number of acres planted by the farmer (1000 acres); OWNRENT is a ratio of the number of acres owned divided by the total number of acres planted; YIELD is the farm-average cotton lint yield (1,000 lb); COLLEGE = 1 if the farmer attended college, and 0 otherwise; OVER50 = 1 if the farmer is over 50 years of age; and 0 otherwise; COMPUTER = 1 if the farmer used a computer for farm management, and 0 otherwise; PROFITABLE = 1 if the farmer thought precision farming was profitable on their fields, and 0 otherwise; IMPORTANCE is an ordinal rating of how important the farmer thought precision farming would be in his/her state five years in the future for cotton, corn, peanuts, rice soybeans, tobacco, and wheat, ranging from unimportant (1) to very important (5) for each crop. The farmer's importance rating for a crop was weighted by the number of acres of that crop, giving a weighted average importance rating for the farmer ranging from unimportant (1) to very important (5) (the sum of the crop weights equaled one); AL = 1 if the farm was located in Alabama, and 0 otherwise; FL = 1 if the farm was located in Florida, and 0 otherwise; GA = 1 if the farm was located in Georgia, and 0 otherwise; MS = 1 if the farm was located in Mississippi, and 0 otherwise; and NC = 1 if the farm was located in North Carolina, and 0 otherwise. The location variable for Tennessee was excluded and was reflected in the intercept. β_0 through β_{22} are parameters to be estimated; ϵ is an error term with a logistic distribution; and i is a subscript representing the i_{th} farmer.

Yield monitoring is used to determine the yield of a crop at different locations within a field (Plant). When used in conjunction with a GPS receiver (YMGPS), the yield of specific areas in the field can be mapped, differentiating the areas of a field that are more productive from those that are less productive (Pierce et al.). Once less productive areas of a field are identified, the farmer can attempt to determine the root cause of low yields. Thus, the spatial variability discovered from yield monitoring can help a farmer to identify areas of a field that may have N deficiencies or where N need not be applied. Farmers using yield monitors with or without GPS were expected to rank the importance of PF technologies in improving the efficiency of N use higher, therefore β_1 and β_2 were expected to be positive. Even without GPS (YMNOGPS), yield monitoring can improve a farmer's knowledge of a field and help in making decisions about N applications.

Remote sensing (REMOTE) can be used to identify soil properties, monitor plant growth and development, and detect environmental stresses, which may limit crop productivity (Dobermann et al.). Remote sensing may be important for discovering spatial variability of N. Soil properties, such as N content, are almost always positively correlated with organic matter content, which can be determined through the use of remote sensing (Schepers, Schlemmer, and Ferguson). Remote sensing is able to show the variation in N during the growth season of a crop. Lower yields caused by N deficiencies can be identified from remotely sensed images. As a result of the potential benefits from using remote sensing in improving the efficiency of N use, β_3 was expected to be positive.

Mapping topography (MAP) is useful in determining the effect that topographical features have on the spatial variability of N. Landscape topography affects soil physical and chemical properties by erosion and deposition processes (Iqbal et al.). Topography affects soil properties, with those properties varying on slopes and in low lying areas. N may also be removed from slopes through tillage and the process of erosion. Farmers can use topographical maps to help in identifying the cause of reduced yield or areas of a field that may need more intense management of N. Therefore, the sign for β_4 was expected to be positive.

Precision soil sampling improves the analysis of field soil properties by determining the spatial variation of the measured properties within the field (Rains, Thomas, and Vellidis). Grid soil sampling (SOILG) involves the development of a uniform grid over the field and sampling within each grid. The other precision soil sampling technique (SOILM) uses historical data, yield maps, aerial photos, and a farmer's general knowledge of field variation to divide the field into management zones with different yield response potentials. Each management zone is treated as an area with homogeneous properties (Rains, Thomas, and Vellidis). Management zone soil sampling draws one or more soil samples from each zone. The number of soil samples taken is usually less when management zone soil sampling is used, resulting in lower soil sampling costs. Precision soil sampling provides information about the spatial variability of N concentrations within a field. As a result, farmers can apply N at varying rates throughout the field according to crop needs, increasing the efficiency of N fertilization. Farmers who used grid or management soil sampling were expected to rank the importance of PF technologies in improving the efficiency of N fertilization higher; therefore β_5 and β_6 were expected to be positive.

On-the-go sensing (ONTHEGO) can be used to determine spatial variability in N concentrations throughout a field. Adamchuk et al. analyzed different on-the-go sensing technologies, many of which were useful in identifying fertilizer deficiencies. On-the-go sensing for N can be of great benefit to farmers. Grid soil sampling costs are expensive. Using on-the-go sensors to measure N concentrations could reduce the costs of soil sampling and result in a higher density of sample measurements. Farmers using on-the-go sensing were expected to rank the importance of PF technologies in improving the efficiency of N fertilization higher. Thus, the sign for β_7 was expected to be positive.

Plant notes the importance of plant tissue samples (TISSUE) in determining if plant fertilizer needs are being met. Bell et al. analyzed tissue sampling to determine if cotton fertilizer needs were being met. They found that tissue sampling was useful in identifying fertilizer deficiencies in cotton. Tissue testing can help farmers identify whether fertilizer deficiency is the cause of low yield in one or more areas of a field. Random samples can also be taken to determine if crop fertilizer needs are being met. These samples can be collected from uniform grids or from management zones within a field. Farmers using plant tissue testing to gather spatial information were expected to rank the importance of PF technologies in improving the efficiency of N fertilization higher, resulting in β_8 being positive.

A review of literature helped identify potential farm and farmer characteristics that may influence technology perceptions and aided in the creation of hypotheses about their impact on farmers' perceptions of PF technologies in the more efficient use of N. Farm size (FARMSIZE) was expected to positively affect farmers' perceptions of the importance of PF technologies in using N more efficiently ($\beta_{10} > 0$). Larger farm size has been associated with higher adoption rates for certain crops (Cowan). Farmers with more acreage and fields have greater opportunities to observe spatial variability in soil N concentrations (Larkin) and are more likely to benefit from greater efficiency in the application of N through the use of PF technologies than other farmers. The ratio of the number of acres owned divided by the total number of acres farmed (OWNRENT) was expected to have a negative effect on farmer perceptions ($\beta_{11} < 0$), meaning that adopters who own a larger proportion of the land that they farm are expected to have lower perceptions of PF technologies in using N more efficiently than those who rent a larger proportion of their land. Adopters who rent a larger proportion of their land may have limited knowledge of the soil characteristics on rented land. Adopters may experience a large increase in knowledge about N spatial variability on rented land from the use of PF information gathering technologies. The knowledge gained about N spatial variability can be used for variable rate application of N, which can lead to increased N efficiency. This increase in efficiency would likely have a positive impact on adopters' perceptions of the importance of information provided by PF technologies in using N more efficiently on rented land. Farmers are more likely to manage land they own more intensely than rented land and therefore perceive PF technologies to be of greater importance for managing owned land. Yield (YIELD) was expected to have a positive influence on farmers' perceptions of PF technologies ($\beta_{12} > 0$). Higher average land quality may indicate greater opportunities for spatial yield response variability, thus having a positive impact upon perceptions.

Because the use of PF technologies requires considerable analytical abilities, those who have attended college (COLLEGE) may have higher perceptions of the importance of PF technologies in the efficient use of N because they are more able to recognize and reap the benefits of PF technologies, leading to the perception of greater importance of PF technologies in improving the efficiency of N fertilization ($\beta_{13} > 0$). Older farmers typically have shorter planning horizons, are resistant to change, and have less exposure to the technologies required for PF (Roberts et al., 2004). These characteristics suggest that older farmers are more risk averse (Dimara and Skuras), which would likely have a negative impact on farmers' perceptions of PF technologies in increasing N efficiency. In this study, older farmers with shorter planning horizons were already adopters of PF technologies, suggesting that they may have been less risk averse than younger adopters. Older farmers have also been farming longer than younger farmers, providing them more experience in recognizing improvements in N efficiency from the use of PF technologies and thus they may have higher perceptions of their importance. Therefore, the sign of OVER50 could not be determined *a priori* ($\beta_{14} <=> 0$). Computer use for farm management (COMPUTER) was expected to have a positive influence on the perception of PF technologies in the more efficient use of N because computers are integral components in the use of PF technologies ($\beta_{15} > 0$).

The perceived profitability (PROFITABLE) of PF was expected to affect farmers' perceptions of PF technologies. Higher profits could result because of increased yields and/or lower costs from the use of PF technologies in applying N more efficiently. Higher profits resulting from more efficient N use would lead to an increase in farmer utility. This increase in utility could result in farmers having higher perceptions of the importance of PF technologies in using N more efficiently. Therefore, perceived profitability was expected to have a positive influence on the perception of PF technologies in the more efficient use of N ($\beta_{16} > 0$). Adopters who felt that precision farming of cotton, corn, peanuts, rice, soybeans, tobacco, and wheat would be important five years in the future (IMPORTANCE) were expected to have higher perceptions of the importance of PF technologies in the more efficient use of N ($\beta_{17} > 0$). Adopters who are more optimistic about the future of PF technologies may have higher utility for PF technologies, increasing their perceptions of PF technologies in efficient P and K fertilization. Location variables AL, FL, GA, MS and NC were included to test whether farmers using PF technologies in Alabama, Florida, Georgia, Mississippi, and North Carolina had higher or lower probabilities of having positive perceptions of PF technologies in the more efficient use of N relative to farmers in Tennessee (Larkin et al.; Roberts et al., 2004). The expected signs for β_{18} through β_{22} were not specified. The survey data were allowed to identify location differences that were present.

Results

Results from estimating equation (4) are reported in Tables 2 and 3 (Appendix). The Chi-squared statistic of 35.80 (Table 3) was significant at the $\alpha = 0.05$ level, indicating that we reject the null hypothesis that all regressors in the model are zero. Multicollinearity diagnostics revealed that multicollinearity was not a problem (Belsley, Kuh, and Welsch). The model correctly predicted 40.7 % of the responses.

Several of the information gathering technologies were statistically significant at the $\alpha = 0.01$ level. The coefficients and marginal effects for the information gathering technology variables are reported in table 2. Four significant variables had their hypothesized signs (SOILG, SOILM, YMNOGPS, ONTHEGO). The coefficients for grid soil sampling (SOILG) and management zone soil sampling (SOILM) were positive, suggesting that PF farmers who had adopted grid soil sampling and management zone soil sampling found the information provided by these technologies to be important in using N more efficiently. Table 2 shows the marginal effects of each ordinal category for grid soil sampling. The negative marginal effect for y = 0 means that farmers using grid soil sampling were less likely to fall into the lowest ordinal category. The positive marginal effect showing the probability that y = 4 means that farmers using grid soil sampling were more likely to fall into the highest ordinal category. The negative effect for the lowest ordinal category and the positive effect for the highest ordinal category for grid soil sampling indicate a rightward shift in the probability distribution. The effect is an unambiguous shift of some probability out of the lower ordinal category and more probability into the higher ordinal category, with the effect of the middle categories (y = 1,2, and 3) being ambiguous. The sign for on-the-go sensing (ONTHEGO) was significant and positive, suggesting that PF adopters who had adopted on-the-go sensing found PF technologies important in using N more efficiently. Marginal effects show that farmers who used on-the-go sensing were more likely to fall into the highest ordinal category and less likely to fall into the lowest ordinal category. The sign for yield monitoring without GPS (YMNOGPS) was also significant and positive, suggesting that PF adopters using yield monitoring without GPS found the information provided by this technology to be important in using N more efficiently. Mapping topography, slope, soil depth, etc. was significant and negative, opposite the hypothesis, suggesting that adopters who used mapping topography, slope, soil depth, etc. did not find the information provided by this technology to be important in using N more efficiently. YMGPS, REMOTE, TISSUE, and SOILSUR were all insignificant, meaning that they had neither a positive nor a negative effect upon adopters' perceptions of PF technologies in using N more efficiently.

The coefficients and marginal effects for the farm and farmer characteristics variables are reported in Table 3. OVER50 was positive and significant, suggesting that adopters over the age of 50 have higher perceptions of the PF technologies they were using in more efficient N fertilization. Marginal effects for OVER50 show that adopters over the age of 50 are more likely to have higher perceptions of PF technologies in using N efficiently. The positive coefficient for OVER50 suggests because older adopters have more experience farming since they have been farming longer, they may be able to recognize an improvement in the efficiency of N use from the use of PF technologies, thus increasing their perceptions of the importance of the PF technologies in more efficient N fertilization.

One farm and farmer characteristic variable had the hypothesized sign. The coefficient for OWNRENT was negative, suggesting that adopters who owned a larger portion of the land they farmed did not consider the information provided by PF technologies to be as important in more efficient N fertilization. This finding suggests that PF technology adopters who are renting a larger proportion of their land found PF technologies to be useful in increasing the knowledge of N spatial variability on rented land, leading to more efficient N use.

Two of the location variables were significant. The signs of the coefficients for farms located in Georgia (GA) and Mississippi (MS) were positive. This suggests that farmers located in Georgia and Mississippi were more likely to have positive perceptions of the PF technologies they are currently using in more efficient N fertilization than farmers who are located in Tennessee. YIELD, COLLEGE, COMPUTER, PROFITABLE, IMPORTANCE, and FARMSIZE were insignificant variables, meaning that they have neither a positive nor negative impact upon farmers' perceptions of PF technologies in using N more efficiently. Location variables for Alabama (AL), Florida (FL), and North Carolina (NC) were not significant, indicating that farm location in any of these states has no impact upon farmers' perceptions of PF technologies in the more efficient use of N relative to farms in Tennessee.

Summary and Conclusions

Farmers who had adopted PF technologies were asked to rate the decision-making value of the technologies that they had used by indicating from 1 (not important) to 5 (very important) how important they felt the information from using these technologies was in reducing N use. Sixty-one percent of farmers responded with an answer of 4 or 5 to the question, meaning that these farmers found the information provided by PF technologies to be important in using N more efficiently.

The results from the ordered logit model suggest differences in the probability of farmers' having higher perceptions of PF technologies in using N more efficiently. Of the information gathering technologies, farmers who used mapping topography, slope, soil depth, etc. did not find the information provided by this technology to be useful in using N more efficiently. The results did show that farmers are more likely to find the information provided by yield monitoring without GPS, management zone soil sampling, grid soil sampling, and on-the-go sensing important in using N more efficiently. Adopters who were using mapping topography were not as likely to have positive perceptions of the importance of PF technologies in using N more efficiently. This suggests that farmers would benefit the most from using yield monitoring without GPS, management zone soil sampling, grid soil sampling, and on-the-go sensing to apply N more efficiently, which could improve profits and minimize environmental impacts.

Adopters who rent a larger proportion of the land that they farm were more likely to have positive perceptions of PF technologies in using N more efficiently. This finding suggests that PF technology adopters who are renting a larger proportion of their land found PF technologies to be useful in increasing the knowledge of N spatial variability on rented land, leading to more efficient N use.

Because younger farmers are typically less risk averse than older farmers (Dimara and Skuras), they may be more likely to adopt PF technologies than older farmers. The results of this research indicate that older farmers who had already adopted at least one PF technology were more likely to have positive perceptions of those PF technologies in using N more efficiently. This finding suggests that extension personnel would have a higher than expected likelihood of success in targeting older farmers for education about

PF technologies in using N more efficiently since older farmers currently using PF technologies were more likely to have positive perceptions of those technologies in using N more efficiently.

Adopters in Georgia and Mississippi were more likely to have positive perceptions of the importance of PF technologies in increasing N efficiency than farmers located in Tennessee. This finding suggests that extension personnel in Georgia and Mississippi would have a higher success rate in educating farmers about the use of PF technologies in using N more efficiently than extension personnel in Tennessee.

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Appendix

Table 1. Definitions of Variables and Means for N Model

	Mean	Definition
Dependent Variable		
N	2.64	Farmer rating of how important the information provided by PF technologies was in reducing N use (not important = 0; very important = 4)
Explanatory Variables		
Information gathering technologies		
YMGPS	0.27	Used yield monitoring with GPS (yes = 1; no = 0)
YMNOGPS	0.26	Used yield monitoring without GPS (yes = 1; no = 0)
REMOTE	0.10	Used satellite images and/or aerial photos (yes = 1; no = 0)
MAP	0.08	Used mapping topography, slope, soil depth, etc. (yes = 1; no = 0)
SOILM	0.42	Used management zone soil sampling (yes = 1; no = 0)
SOILG	0.58	Used grid soil sampling (yes = 1; no = 0)
ONTHEGO	0.02	Used on-the-go sensing (yes = 1; no = 0)
TISSUE	0.43	Used plant tissue testing (yes = 1; no = 0)
SOILSUR	0.42	Used soil survey maps (yes = 1; no = 0)

Table 1 Continued

		Mean	Definition
Farm and farmer characteristics			
	FARMSIZE	2.47	Total acres planted (1,000 acres)
	OWNRENT	0.39	Acres owned divided by total acres planted
	YIELD	0.71	Farm average cotton lint yield (1,000 lb)
	COLLEGE	0.81	Attended at least one year of college (yes = 1; no = 0)
	OVER50	0.29	Farmer age over 50 (yes = 1; no = 0)
	COMPUTER	0.68	Used a computer for farm management (yes = 1; no = 0)
	PROFITABLE	0.61	Farmer thought that PF was profitable on their fields (yes = 1; no = 0)
	IMPORTANCE	3.89	Farmer thought that PF would be unimportant (1) to very important (5) in his/her state in five years
Farm location			
	AL	0.22	Farm located in Alabama (yes = 1; no = 0)
	FL	0.04	Farm located in Florida (yes = 1; no = 0)
	GA	0.16	Farm located in Georgia (yes = 1; no =)
	MS	0.21	Farm located in Mississippi (yes = 1; no = 0)
	NC	0.29	Farm located in North Carolina (yes = 1; no = 0)

Table 2. N Model Ordered Logit Estimates and Marginal Effects for Information Gathering Technologies

Variable	Coefficient[a]	Marginal Effects for Ordinal Categories				
		y = 0	y = 1	y = 2	y = 3	y = 4
CONSTANT	0.698	N/A[b]	N/A	N/A	N/A	N/A
YMGPS	0.149	-0.007	-0.007	-0.020	0.009	0.025
YMNOGPS	0.808*	-0.033	-0.032	-0.108	0.025	0.147
REMOTE	-0.605	0.036	0.032	0.078	-0.060	-0.085
MAP	-1.637**	'0.148	0.102	0.137	-0.212	-0.175
SOILM	0.758*	-0.035	-0.033	-0.102	0.041	0.129
SOILG	0.837*	-0.043	-0.040	-0.110	0.061	0.132
ONTHEGO	2.154*	-0.046	-0.048	-0.211	-0.178	0.483
TISSUE	-0.272	0.013	0.012	0.037	-0.019	-0.044
SOILSUR	-0.026	0.001	0.001	0.004	-0.002	-0.004
n	135					
χ^2 22 df	35.80***					

[a] ***, **, and * indicate statistical significance at the $\alpha = 0.10$, $\alpha = 0.05$, and $\alpha = 0.01$ levels, respectively.

Table 3. N Model Ordered Logit Estimates and Marginal Effects for Farm and Farmer Characteristics

Variable	Coefficient[a]	Marginal Effects for Ordinal Categories				
		y = 0	y = 1	y = 2	y = 3	y = 4
FARMSIZE	-0.016	0.001	0.001	0.002	-0.001	-0.002
OWNRENT	-1.609***	0.077	0.073	0.220	-0.105	-0.264
YIELD	0.284	0.014	0.013	-0.039	0.019	-0.047
COLLEGE	-0.729	0.029	0.028	0.097	-0.019	-0.135
OVER50	1.036***	-0.042	-0.041	-0.136	0.028	0.191
COMPUTER	-0.113	0.005	-0.005	0.015	-0.007	0.019
PROFITABLE	0.122	-0.006	-0.006	-0.017	0.008	0.020
IMPORTANCE	0.277	-0.013	-0.013	-0.038	0.018	0.046
AL	0.924	-0.036	-0.035	-0.121	0.018	0.174
FL	1.127	-0.035	-0.035	-0.139	-0.027	0.236
GA	1.752**	-0.054	-0.054	-0.204	-0.055	0.367
MS	1.462**	-0.051	-0.050	-0.181	-0.009	0.291
NC	1.018	-0.041	-0.040	-0.134	0.028	0.187
$\mu 1$	0.782***					
$\mu 2$	2.352***					
$\mu 3$	4.280***					

[a] ***, **, and * indicate statistical significance at the $\alpha = 0.01$, $\alpha = 0.05$, and $\alpha = 0.10$ levels, respectively.

Part 4: Summary

This study analyzed the factors that affected PF technology adopters' perceptions of the importance of PF technologies in using P, K, and N more efficiently using an ordered logit model. The results of the P and K model indicate that, of the information gathering technologies, farmers who used remote sensing and mapping topography, slope, soil depth, etc. did not find the information provided by these technologies useful in reducing P and K use. The results did show that farmers found management zone soil sampling, grid soil sampling, and on-the-go sensing more important in using P and K more efficiently.

Of the farm and farmer characteristics for the P and K model, the results indicated that adopters over the age of 50 were more likely than adopters under the age of 50 to have positive perceptions of PF technologies in using P and K more efficiently. Since older farmers may have more experience than younger farmers, they may be able to recognize an improvement in the efficiency of P and K. Adopters who were using a computer for farm management were more likely to have positive perceptions of PF technologies in using P and K more efficiently, suggesting that adopters using computers for farm management may observe greater changes in P and K efficiency. Adopters who rented a larger proportion of the land they farmed were more likely to have positive perceptions of PF technologies in more efficient P and K fertilization. This finding suggests that farmers renting a higher proportion of the land they farm may have higher perceptions of PF technologies in using P and K more efficiently due to the increase in knowledge of P and K spatial variability on rented land.

The results of the N model indicate that, of the information gathering technologies, adopters who used mapping topography, slope, soil depth, etc. did not find the information provided by this technology to be useful in using N more efficiently. The results did show that farmers who used grid soil sampling, management zone soil sampling, yield monitoring without GPS, and on-the-go sensing found these technologies to be more important in using N more efficiently.

Farm and farmer characteristics show that adopters over the age of 50 using at least one PF technology were more likely to have positive perceptions of those PF technologies in using N more efficiently, suggesting that since older adopters have, in all likelihood, been farming longer than adopters under the age of 50, they may be able to recognize greater improvements in N efficiency. Those adopters who rented a larger proportion of the land they farmed were more likely to have positive perceptions of PF technologies in more efficient N fertilization. This finding suggests that farmers renting a larger proportion of the land they farm may have higher perceptions of PF technologies in using N more efficiently since the use of PF information gathering technologies can increase the knowledge about N spatial variability. Adopters in Georgia and Mississippi were more likely to have positive perceptions of the importance of PF technologies in increasing N efficiency than farmers located in Tennessee.

Information from this study will be useful for farmers interested in applying fertilizer in a more efficient manner for increased profits and reduced negative environmental impacts. In the future a similar study could be used to analyze farmers' perceptions relating to more efficient fertilizer use and the environment.

Vita

John Colby Torbett was born in Johnson City, Tennessee, on July 15, 1982 to Phillip and Denise Torbett. He was raised in Piney Flats, Tennessee and attended schools in the public school system of Sullivan County, Tennessee, where he graduated from Sullivan East High School in May 2000.

In August of 2000, he entered the University of Tennessee, Knoxville. In May of 2004 he received a Bachelor of Science in Agriculture degree with a major in Agricultural Economics. In August of 2004 he entered the Master's program in the Department of Agricultural Economics at the University of Tennessee, Knoxville. Colby received his Master of Science degree in Agricultural Economics in May 2006. During both his undergraduate and graduate study, Colby took various courses in a variety of subject areas including, but not limited to: agricultural economics, animal science, economics, food science, crop science, statistics, finance, and agricultural policy.