

EVALUATING ADOPTION AND USES
OF PRECISION FARMING TECHNOLOGIES

A Thesis

Presented in Partial Fulfillment of the Requirements for
the Degree Master of Agricultural, Environmental, and Development Economics in the
Graduate School of The Ohio State University

By

Michael W. Arnholt, B.S.

The Ohio State University
2001

Master's Examination Committee:

Dr. Marvin T. Batte, Adviser

Dr. D. Lynn Forster

Approved by

Adviser

Department of Agricultural, Environmental,
and Development Economics

ABSTRACT

Precision farming technology (PF) is designed to provide information and data to assist farmers when making site-specific management (SSM) decisions. By making more informed management decisions, farmers can become more efficient, lower costs, and become more profitable. However, little is known about how farmers use PF to make management decisions, identify production problems, and about the relative magnitude of benefits and costs of PF on individual farms. Therefore, research is needed to find answers to questions surrounding the adoption, uses, and the potential management benefits of PF in Ohio.

First, an embedded, multiple-case study approach was used to collect information about PF from six different farms, which fit specific criteria. The objective was to collect information about adoption and use of PF from early adopters to glean information that would be useful to those considering PF adoption.

Next, a survey questionnaire was sent to a group of 156 PF patrons of a central Ohio cooperative. The objectives were to understand PF adoption motivation, how farmers use their PF system, what system components they have adopted, the perceived benefits and costs related to adoption, and changes in management practices. The numerical rankings and data collected were analyzed through statistical measures using

the Statistical Analysis System (SAS). Four regression models were constructed from the survey data to statistically test hypotheses involving motivational, cost, and benefit factors, and various management changes.

The results show that the most important factor driving PF adoption was to increase profits. The most frequently adopted components were grid soil sampling and VRT application of lime. VRT seeding and pesticide application lagged behind the adoption rates of VRT fertilizer and lime. The most important benefits from adoption were a more precise knowledge of soil pH and crop yield variability. Costs associated with adoption are mixed and inconsistent. Both studies indicate that fertility management practices are the most likely to change as a result of PF adoption, as compared to planting and pesticide practices. Results suggest that farmers who adopt PF are satisfied with their PF system and will continue to adopt additional components.

I wish to dedicate this to my parents, Earl and Cynthia Arnholt.

ACKNOWLEDGMENTS

I would like to thank my adviser Marvin Batte for his guidance, dedication, and patience. Thank you for taking the time to explain concepts, correct my mistakes, and for all your assistance along the way. I truly appreciate it.

I would like to thank D. Lynn Forster who also served on my graduate research committee. Thank you for sharing your ideas, comments, and view points.

I would also like to thank LeeAnn Moss and Stan Ernst for their assistance and input in designing the survey questionnaire.

Also, thanks go out to several Ohio State University Extension agents throughout the state for their input and assistance throughout the research. Thanks go to the central Ohio cooperative for their help as well.

The research and financial support from the U.S. Department of Agriculture Grant No. 97-36200-5239, *Economic and Environmental Evaluation of Site Specific Farming Technologies* and by the Fred N. VanBuren Program of Farm Management, The Ohio State University, is gratefully acknowledged.

Special thanks go to Renae for her support, patience, and kind words as I wrote this thesis.

VITA

September 9, 1973Born – Berea, Ohio

1995B.S. Agriculture, The Ohio State University

1999-2001Graduate Research Associate, Department of
Agricultural, Environmental, and Development
Economics, The Ohio State University

FIELDS OF STUDY

Major Field: Agricultural, Environmental, and Development Economics

TABLE OF CONTENTS

	<u>Page</u>
Abstract	ii
Dedication	iv
Acknowledgments	v
Vita	vi
List of Tables.....	x
List of Figures	xii
Chapters:	
1. INTRODUCTION.....	1
Problem Identification.....	2
Objectives and Hypotheses	3
2. LITERATURE REVIEW.....	5
Review of Precision Farming Technology.....	5
3. METHODOLOGY AND PROCEDURE	10
Review of Case Study Methods in Agricultural Economics.....	10
Case Study Method and Procedure	12
Survey Procedure	23
4. INDIVIDUAL CASE STUDY SUMMARIES	26
Case Study #1: Ted Jones.....	27
Background	27
Adoption and Motivation	31
Information and Management Practices.....	34
Successes, Disappointments, and Problems.....	39
Future Goals and Conclusions	41

Case Study #2: Andy Smith	42
Background	42
Adoption and Motivation	42
Information and Management Practices.....	43
Successes, Disappointments, and Problems.....	47
Future Goals and Conclusions	47
Case Study #3: Mike Gate.....	48
Background	48
Adoption and Motivation	49
Information and Management Practices.....	52
Successes, Disappointments, and Problems.....	53
Future Goals and Conclusions	54
Case Study #4: Jim King.....	55
Background	55
Adoption and Motivation.....	56
Information and Management Practices.....	58
Successes, Disappointments, and Problems.....	60
Future Goals and Conclusions	60
Case Study #5: Todd Hall	61
Background	61
Adoption and Motivation	62
Information and Management Practices.....	64
Successes, Disappointments, and Problems.....	66
Future Goals and Conclusions	67
Case Study #6: Steve Brown.....	68
Background	68
Adoption and Motivation	69
Information and Management Practices.....	71
Successes, Disappointments, and Problems.....	73
Future Goals and Conclusions	74
Cross-Case Summary	75
Background	75
Adoption and Motivation	78
Information Gained	80
Management Practices.....	80
The Changing of Management Practices	83
Successes, Disappointments, and Problems.....	84
Future Goals and Conclusions	85
5. A SURVEY OF CENTRAL OHIO PRECISION FARMERS	88
Grower Profile.....	89
Component Adoption	92
Adoption Motivation.....	94
Relative Benefits and Costs by PF Component	97
Field Variability	99

Costs Associated with Precision Farming Adoption.....	101
Benefits Associated with Precision Farming Adoption	103
Benefits and Costs of Entire PF System.....	103
Changes in Management Practices.....	107
Satisfaction, Profitability, and Future of PF.....	109
Multivariate Regression Analysis	111
Benefits and Costs Model	111
Fertility Management Change Model	117
Pesticide Management Change Model.....	122
Planting Management Change Model.....	125
6. FINAL RESULTS AND CONCLUSIONS	128
Major Conclusions from the Case Studies	130
Major Conclusions from the Survey	133
Overall Conclusions	137
Limitations	139
Appendices:	
A. Case Study Questionnaire	140
B. Case Study Data Collection Sheets	154
C. Survey Questionnaire by Mail.....	162
List of References.....	173

LIST OF TABLES

<u>Table</u>	<u>Page</u>
Table 1: Summary of Farming Business.....	29
Table 2: Agricultural Services Purchased Before Adoption of PFT	31
Table 3. PFT Currently Adopted and Using – Ted Jones	32
Table 4. Primary Motivational Factors Behind Adoption of PFT.....	33
Table 5. Key Information Gained from Entire PF System.....	35
Table 6. Summary of How PF has Changed Management Practices.....	38
Table 7. Information Sources relied upon when having Problems with PF System.....	40
Table 8. PFT Currently Adopted and Using – Andy Smith.....	44
Table 9: PFT Currently Adopted and Using – Mike Gate	51
Table 10: PFT Currently Adopted and Using – Jim King.....	57
Table 11: PFT Currently Adopted and Using – Todd Hall	63
Table 12: PFT Currently Adopted and Using – Steve Brown.....	70
Table 13: General Summary of Growers Surveyed	90
Table 14: Farmer Adoption of Precision Farming Technology	93
Table 15: Primary Motivational Factors for Precision Farming Adoption	95
Table 16: Farmer Evaluation of Relative Benefits and Costs for Each PF Component ..	98
Table 17: Field Variability	100

Table 18: Farmer Evaluation of Costs Associated with PF Adoption and Use	102
Table 19: Farmer Evaluation of the Benefits Gained from PF Adoption and Use	104
Table 20: Overall Benefits and Costs of Entire Precision Farming System	106
Table 21: How the PF System Changes Management Practices/Decisions.....	108
Table 22: Satisfaction, Profitability, and Future of Precision Farming	110
Table 23: Regression of Farmer Characteristics and PF Components on BC Ratio.....	115
Table 24: Regression of Fertility Management Changes.....	121
Table 25: Regression of Pesticide Management Changes	124
Table 26: Regression of Planting Management Changes.....	126

LIST OF FIGURES

<u>Figure</u>	<u>Page</u>
Figure 1: Relevant Situations for Different Research Strategies	13
Figure 2: Basic Types of Designs for Case Studies	14
Figure 3: Case Study Method.....	16
Figure 4: OSU Extension Districts.....	28
Figure 5: Effect of Yield Monitor Only and Yield Monitor and GPS Receiver	116
Figure 6: Interaction Effect of VRT Lime and pHvar.....	117

CHAPTER 1

INTRODUCTION

The technology within production agriculture has changed very rapidly during the past several years. Many of these changes have brought about a new technology category known as precision agriculture or precision farming. Precision farming (PF) uses “information technologies to tailor soil and crop management to fit the specific conditions found within a field” (Erickson and Lowenberg-DeBoer ed., p. 1). A report by The National Research Council (1997, p.2) refers to precision agriculture, “...as a management strategy that uses information technologies to bring data from multiple sources to bear on decisions associated with crop production.” Precision farming or precision agriculture differs from many previous technologies within agriculture. PF is comprised of numerous *component technologies* that farmers may adopt as a system. Thus, some farmers may adopt a few components while others may adopt several. PF component technologies include yield monitors, geo-reference grid soil sampling, geo-referenced variable rate technology for lime, fertilizer, and pesticide application, global positioning systems (GPS), and detailed field maps created from geographic information systems (GIS), to name just a few.

The use of new precision farming technology (PFT) allows growers to micro-manage individual grids or management zones in a specific field according to its unique production capabilities. The ability to micro-manage individual grids, zones, or fields is referred to as site-specific farming. Site-specific farming (SSF) is defined as “the time proven idea of crop management: doing the right thing, at the right time, in the right place” (Erickson and Lowenberg-DeBoer ed., page 1).

Precision farming technology is designed to provide extensive information and data to assist farmers when making site-specific management decisions. By making more informed and better management decisions, farmers can become more efficient, lower production costs, and, in turn, become more profitable. However, little is currently known about how farmers use PF technologies to make management decisions or identify production problems, or about the relative magnitude of benefits and costs of PF technologies on individual farms. Therefore, research of precision farming technology is needed to assist the Ohio agricultural community in finding answers to questions surrounding the adoption, uses, and the potential management benefits of precision farming technology.

Problem Identification

Several questions regarding precision farming technology need to be answered to assist the agricultural community in evaluating precision farming technology. Growers want answers to their many questions surrounding PF technologies. **Why** are some farmers choosing to adopt precision farming technology? Which “technology tools” or

components are they adopting? What is/are the driving motivational factor(s) behind adoption and use of each technology tool or component? For which technology components are the benefits exceeding the costs (profitability concerns)? **How** are farmers who adopt PF using the new data and information that have been obtained? Are they using the information to make management practice changes? If so, which management practices are they changing as a direct result of PF component adoption? What types of data and information are they collecting to guide this decision to adopt or not adopt PF component(s)? Who is influencing and assisting with adoption of PF component(s)? Are farmers planning to adopt more or less of the various precision farming technology components in the future? These are several of the key questions that this research will address.

Objectives and Hypotheses

The objectives of this study are to collect information about adoption and use of precision farming from early adopters of this technology and to glean from this information that can be useful to those considering adoption. Specifically, the objectives are as follows:

- 1) To perform exploratory and explanatory case study interviews on six progressive, early adopters of PF components in Ohio to explore, explain, and understand why these farmers adopted and currently use PF technology.
- 2) To understand which technology tools or components have been the most beneficial and valuable (costs vs. benefits) to adopting farmers.
- 3) To evaluate how management practices have changed as a result of adopting and using PF components.
- 4) To discover common characteristics among PF adopters and users.

- 5) To discover adoption rates of individual technology tools.
- 6) To determine current satisfaction or dissatisfaction with individual PF components.
- 7) To determine if current PF users plan to continue to adopt additional PF components in the future.

Hypotheses that will be tested and analyzed include:

- 1) Individual farmers will adopt those technology components of PF that will provide the greatest expected benefits (return) for their specific farming needs.
- 2) The net benefits of PF will vary directly with the level of variability of farm fields.
- 3) The net benefits of PF will vary directly with farm size
- 4) The net benefits of PF will vary directly with the formal education level of the primary operator.
- 5) The net benefits of PF will increase as the number of precision farming component technologies used increases.
- 6) The primary motivational factor behind adoption of PFT is to increase profits.
- 7) Adoption and use of PFT has significantly changed farmers' management and decision practices.
- 8) Farmers who have adopted and currently use PFT will continue to adopt additional PFT in the future.

CHAPTER 2

LITERATURE REVIEW

Review of Precision Farming Technology

Research concerning Precision Farming Technologies is limited due to the relatively recent introduction of this technology to the agricultural community. However, this limited, early research has been valuable in identifying the pros, cons, costs, benefits, and future potential of PF. According to early research by Swinton and Lowenberg-DeBoer, precision farming technology and site-specific farming (SSF) adoption appears to have been rapid and uneven (1998). They observe that very little hard data exists to determine how common PF and SSF practices have become (Swinton and Lowenberg-DeBoer, 1998). Local agribusinesses, county extension agents, Co-ops, and agricultural retailers that have taken a progressive leadership role in educating and promoting potential PF benefits may have substantially encouraged adoption of PF by farmers. Growers that are in business for the long run, should make PF part of their future strategic plan (Swinton and Lowenberg-DeBoer). Precision farming has the potential to be both an output increasing and cost decreasing technology, depending on the specific farm setting within which it is applied. By adopting and using PF, growers may be able

to lower unit costs of production by increasing yields or by increasing input efficiency. Is this the case for farmers in Ohio who have adopted PF?

A more recent study conducted in Illinois, Indiana, Iowa, and Wisconsin shows low current rates of PF adoption (Khanna, Epouhe, and Hornbaker). This four state survey, which did not include Ohio, shows only 20% of growers have adopted an advanced PF system. They found that adopters of PF tend to be younger, more educated, full time farmers, and operate larger sized farms (Khanna, Epouhe, and Hornbaker). The study also suggested that adoption of advanced PF systems is path dependent. In other words, farmers who have adopted computers and diagnostic equipment are more likely to be the early adopters of PF (Khanna, Epouhe, and Hornbaker). Also, 69% of all farmers in this four state study have chosen “a limited adoption strategy by adopting a diagnostic technology but preferring to wait before adopting a variable-rate application technology or a yield monitor” (p. 470). Khanna, Epouhe, and Hornbaker discovered that the low rates of adoption are due to “uncertainty in returns due to adoption, high fixed costs of investment and information acquisition, and lack of demonstrated effects of these technologies on yields, input-use, and environmental performance” (p. 471). However, this four state study on PF adoption does **not** include Ohio growers. Local research in Ohio is needed to answer questions involving precision farming in Ohio.

Profitability of precision farming continues to be difficult to predict and uncertain (Atherton, Morgan, Shearer, Stombaugh, and Ward). Unfortunately, it is not known which of the various components of the technology will prove most practical and profitable (Swinton and Lowenberg-DeBoer). Evidence of their profitability has been missing, or at best, mixed (Swinton and Lowenberg-DeBoer). A study of nine field

research sites by Swinton and Lowenberg-DeBoer, found variable rate fertilizer application to be unprofitable on wheat and barley, sometimes profitable on corn, and profitable on sugarbeets. They concluded that because SSF practices are site-specific, their profitability potential too is site-specific (Swinton and Lowenberg-DeBoer).

Other studies have recognized that PF has the potential to be economically profitable, but the profitability depends heavily on the degree of spatial variability within the field according to such attributes as soil types and yield response variability (Roberts, Burton and Mahajanashetti). These researchers conclude that actual economic returns of variable rate nitrogen application can only be determined on a field-by-field basis because returns depend on the specific attributes of each field. Another study found that variable rate technology only became profitable when the application acreage became large enough that the fixed costs could be spread over this sizeable acreage to take advantage of economies of scale. Actual farm field trials from 1993 to 1995 found that site-specific fertilizer management did not reliably increase returns as a stand-alone practice for corn, soybean, or wheat (Lowenberg-DeBoer and Aghib). This supports a consistent theme that the overall profitability of PF is itself specific to each individual field. PF has the potential to be profitable and the actual results will vary by individual farmer, field, and crop.

Farmers also use PF to document and keep precise records of specific, value added crops. Yield monitors, GPS receivers, and GIS mapping software have assisted farmers with maintaining precise records of the location, acreage, and yields of these crops each year (Swinton and Lowenberg-DeBoer). This technology keeps precise yield record results of various hybrids, varieties, and specific value added crops that require

identity preservation (IP) (Erickson and Lowenberg-DeBoer, ed. 2000). Farmers can keep accurate records on specific value added crops like high oil corn or genetically modified crops like herbicide tolerant soybeans and corn. PF maps and records can help farmers during harvest to ensure the proper segregation of identity preserved crops, like high oil corn and number 2 yellow corn. It is difficult to attach a monetary value to this benefit of PF, but it is clear that this ability to keep these precise records, crop information, and maps can have significant value to some farmers (Khanna, Epouhe, and Hornbaker).

Precision farming methods may also have implications regarding risk management. Lowenberg-DeBoer presented a simple theoretical model that suggested there were circumstances when SSF could reduce whole field yield variability. Empirical evidence from on-farm tests of site-specific fertilizer management supported the hypothesis that SSF can have risk reducing benefits. The data suggest that SSF can reduce the probability of profits falling into the lower profit distribution level (Lowenberg-DeBoer). However, he also recognizes that SSF may increase some risks, including business, financial, human, and technological risks. SSF increases fixed costs, requires more time to learn, and the technology can become obsolete very quickly (Lowenberg-DeBoer). A final point is the fact that much more on-farm empirical work needs to be done to determine the potential for adoption of PF to reduce risks (Lowenberg-DeBoer).

Some studies considered the potential of environmental benefits that may arise from the use of PF. Environmental benefits of variable rate technology (VRT) increase with field fertility variability due to the relative increases in fertilizer use efficiency as compared to the traditional single rate application method (Thrikawala, Weersink,

Kachanoski, and Fox). Site-specific application of fertilizers and pesticides on certain sandy soil types could reduce environmental damage (Atherton, Morgan, Shearer, Stombaugh, and Ward). As with the profitability of PF, environmental benefits of PF may also be site-specific and could play a role in the motivation and adoption of PF.

Most of the early adoption of PF practices has been concentrated in the Midwest because grain yield monitors were on the market before monitors for other crops (Swinton and Lowenberg-DeBoer). Also, about 40% of farmers surveyed in Illinois, Iowa, Indiana, and Wisconsin are willing to adopt yield monitors and VRT sometime within the next five years (Khanna, Epouhe, and Hornbaker). Therefore, the outlook and promise for PFT looks very positive in those states, but what about in Ohio?

Despite the existing foundation of research on PF, many more questions still remain unanswered and unclear for Ohio farmers and agribusinesses. Both farmers and agribusiness are extremely interested in understanding the potential risks, rewards, costs, and benefits behind adoption and use of PF in Ohio. The objectives and goals of this study will help answer these questions and will assist Ohio farmers and agribusiness personnel in making informed decisions in regards to precision farming adoption and use.

CHAPTER 3

METHODOLOGY AND PROCEDURE

This thesis contains two distinct research foci. The first is multiple case studies to consider the motivation, adoption, and uses of PFT. The purpose of this case study research is to explain, understand, and answer the how and why questions motivating adoption, uses, and management changes resulting from precision farming adoption and use among Ohio farmers. The second is a statistical analysis of a survey mailed to precision farming patrons of a central Ohio cooperative. The purpose of this survey research is to understand what PF system components they have adopted, how farmers use their PF system, the costs and benefits of the PF system, and management changes that resulted from PF system adoption. In the following chapter the procedures of this research are discussed.

Review of Case Study Methods in Agricultural Economics

Case studies have been and continue to be used extensively in the various fields of social sciences. A case study is “an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between

phenomenon and context are not clearly evident,” (Yin, page 13). Case studies usually deal with topics that have more variables of interest than data points (Yin).

The increasing use of case study research has raised many questions regarding agricultural economics research methodology (Kennedy and Luzar). Kennedy and Luzar argue that agricultural economics has embraced a consensus methodology, referred to by Randall as “demarcationist prescriptive methodology” (1999). Case study methods do not follow the current, conventional economic methodologies. Because of this, case studies have been faulted for their lack of representation, lack of rigor in collection and analysis of empirical evidence, and the problem of bias (Kennedy and Luzar). However, case studies are becoming more and more “accepted in other social sciences, not as a replacement for theoretical or statistical approaches, but as complements that enhance understanding” (Kennedy and Luzar, page 582). Explaining and understanding “why” and “how” becomes an important question to answer as agricultural economics evolves and relates more to social sciences (Kennedy and Luzar). All these points clearly support the use of case studies in order to explore and understand the objectives identified in this paper.

Case studies can and should be used in agricultural economics for three main reasons. First, case studies use a rigorous approach to explain and understand (Kennedy and Luzar). This can complement the current strength in agricultural economics of prediction. Second, social sciences have developed a rigorous set of protocols for case study research and agricultural economists simply need to learn about and follow these protocols (Kennedy and Luzar). Lastly, as agricultural economics evolves and changes to become more like other social sciences, we need to view this as a challenge, not a threat,

and “embrace methodological inclusivism” so we can sustain and enhance the position of agricultural economics in the future (Kennedy and Luzar). Therefore this paper will use case study method to explain and understand the motivation, cost benefit factors, and management changes surrounding PF adoption and use.

Case Study Method and Procedure

Case studies are useful “when **how** or **why** questions are being posed, when the investigator has little control over events, and when the focus is on a contemporary phenomenon within some real-life context”(Yin 1994, page 1). The case study is an excellent method to use when the objective is to explain and understand phenomenon (Kennedy and Luzar). The case study method differs substantially from statistical methods applied to representative samples, the prevailing methodology for most economic research. It is important to realize that this thesis is not trying to predict or calculate the profitability of PF or construct economic budgets concerning PF. The goal of the case study research reported in this thesis is to explain, understand, and answer the “how” and “why” questions motivating adoption and uses of precision farming, and the management practices that have been changed as a result of PF adoption among Ohio farmers. Results of the case studies will guide formulation of the research survey questionnaire to be used in the second part of this research (figure 1).

Strategy	Form of research question	Requires control over behavioral events?	Focuses on contemporary events?
Experiment	How, Why	Yes	Yes
Survey	Who, What, Where How many, How much	No	Yes
Archival Analysis	Who, What, Where How many, How much	No	Yes/No
History	How, Why	No	No
Case Study	How, Why	No	Yes

Figure 1: Relevant Situations for Different Research Strategies

Source: Case Study Research, Yin, 1994.

Four basic case study designs currently exist (Yin, 1994). The four types of case study designs are: the single-case holistic design, single-case embedded design, the multiple-case holistic design, and the multiple-case embedded design (figure 2).

The single-case design is primarily used in three situations-where the case represents a critical test of existing theory, when the case is unique or rare, or where the case serves a revelatory purpose (Yin, 1994). A multiple-case design is used to build more evidence and therefore is considered more compelling and robust than single-case studies (Yin, 1994). Each case within a multiple-case design is analogous to conducting six to ten experiments on a related topic, which is using replication logic, not sampling logic (Yin, 1994). Survey research relies on statistical generalization using sampling logic, where as case studies rely on analytical generalization gathered from replication

logic. “In analytical generalization, the investigator is striving to generalize a particular set of results to some broader theory” (Yin, 1994, page 36).

Holistic refers to the concept that the case study looks at a single unit of analysis that includes the whole, global, or entire picture. Embedded design refers to multiple units of analysis. “For instance, even though a case study might be about a single public program, the analysis might include outcomes from individual projects within the program” (Yin, p. 41, 1994). “In an organization study, the embedded units also might be process units-such as meeting, roles, or locations” (Yin, 1994 p. 41). “The resulting design would be called an embedded case study design” (Yin, 1994 p. 42). “In contrast, if the case study examined only the global nature of a program or of an organization, a holistic design would have been used” (Yin, 1994, p. 42).

	Single-Case Designs	Multiple-Case Designs
Holistic (single unit of analysis)	Type 1	Type 3
Embedded (multiple units of analysis)	Type 2	Type 4

Figure 2: Basic Types of Designs for Case Studies
Source: Case Study Research, Yin, 1994.

A multiple-case, embedded design was used in this case study. The multiple-case study, meaning multiple cases or “experiments”, was made up of individual case studies that were conducted on six farmers who have adopted and use PF. Embedded, meaning multiple units of analysis, include the many PF dynamics surrounding each individual

farmer. The embedded or multiple units of analysis include: motivational factors behind PF adoption, the various PF components that have been adopted, management practices that have changed as a result of PF adoption and use, and future plans with PF.

“For case studies, theory development as part of the design phase is essential, whether the ensuing case study’s purpose is to develop or to test theory” (Yin, 1994, p. 27). A theory needs to be developed first. Yin states that case studies benefit from prior development of theories to guide data collection and analysis (1994) (figure 3).

The theory guiding this case study research is that farmers are motivated, adopt, use PF, and change management practices for many reasons. The primary reason is derived from the principle theory of utility maximization. We assume that farmers act rationally and are trying to achieve maximum utility through the everyday decisions they make. These rational utility maximizing factors are directly linked to returns and profits. Economies of size influence returns and impact the rational farmer’s decision process and decisions are also influenced by the risk that an individual is willing to take. By using an exploratory and explanatory case study method, the answers to the how and why questions surrounding PF adoption and uses will be identified.

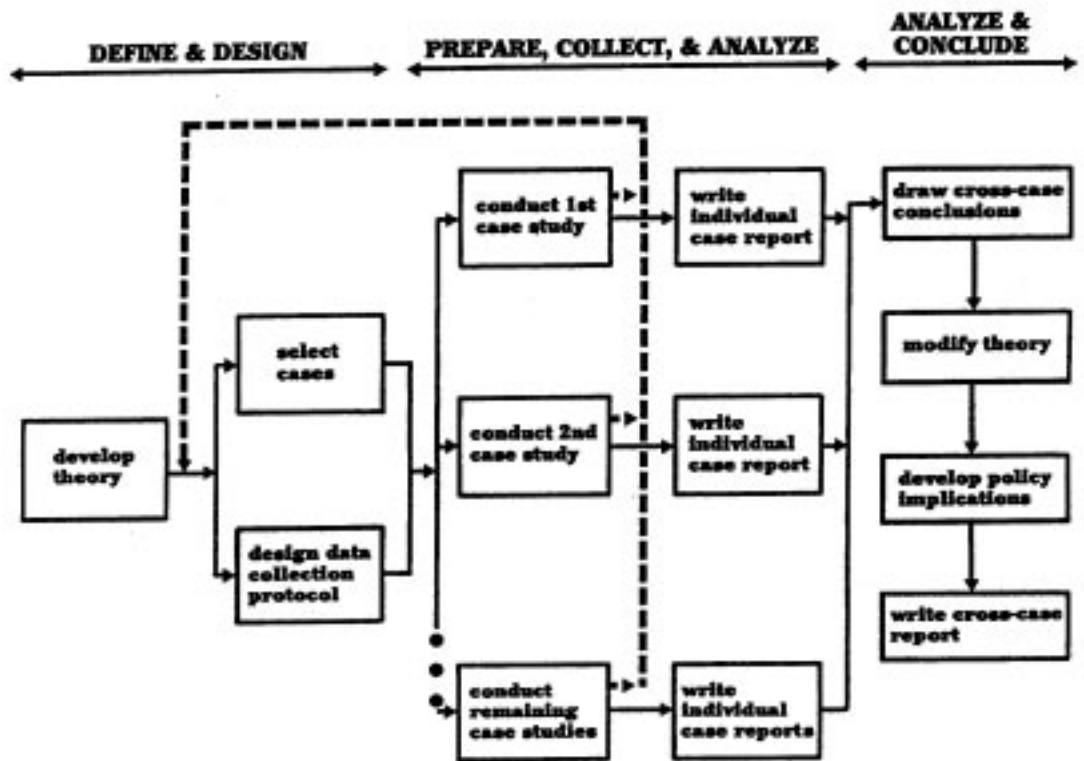


Figure 3: Case Study Method
 Source: Case Study Research, Yin, 1994.

Next, the case study method calls for case selection. In the case selection process, a common random sample is not chosen (Yin, 1994). Instead a sample is chosen that suits specific and defined criteria. Since case studies are used to explore or explain, the individual case or cases must fit the specific criteria that are needed to answer, explain, or test the hypotheses (Yin, 1994).

In this multiple-case study, six adopters of PF were selected as the cases based on specific criteria. The specific criteria were the farmers must have adopted at least three or more precision farming technologies and have been using PF for at least two years. Also, local OSU extension agents were used to assist with grower selection and initial grower contact to convince the growers to participate in this case study. The six case study interviews would help find answers to the how and why questions and explore the adoption and uses of PF.

Following the six individual case selection process, a data collection protocol was designed. Yin points out the importance that the researcher identify and follow a set of rules using a data collection protocol before collecting evidence (1994). The data collection protocol sets the rules and guidelines for data collection in the case studies. These rules and guidelines assist in limiting bias and add a consistent structure to the entire data collection process. Yin points out the importance of editing and revising the questions asked during the case interviews. Also, sharp listening skills are essential during the interviews in order to make comparisons and summaries of the cases. A clear understanding of the topic being studied is important when interviewing as well (Yin,

1994). Finally, limiting bias is of utmost importance. The subjects being interviewed should not be lead by the interviewer (Yin, 1994).

The data collection protocol for the six case studies includes: 1) the case study questionnaire in appendix A was administered by the same researcher during each interview. The questionnaire was constructed by conducting an extensive literature review on PF. The PF literature review examined previous studies concerning adoption, profitability, costs, benefits, problems and other issues concerning PF. From this review, a case study questionnaire was developed to find answers to the objectives previously identified. 2) An open ended question and discussion format was used by the researcher during the interviews, 3) the researcher remained flexible and open-minded as the interviewee answered the questions to limit bias, 4) the researcher had a firm grasp and knowledge base of the PF issues being studied, 5) careful attention was made to avoid any “leading” of farmers being interviewed, 6) researchers focused on listening and avoided making unnecessary comments during interviews, and 7) data collection sheets in appendix B were used to capture ranking information on specific questions. These rules helped limit biased results from occurring and aided in the collection of qualitative, multiple-case study data.

Collecting evidence is the next step in the case study process. There are six primary sources used in collecting evidence. The sources include: documentation, archival records, interviews, direct observation, participant observation, and physical artifacts (Yin, 1994). Some case studies are successful and well done by focusing on a single source for evidence collection, while other case studies may use several of these evidence sources (Yin, 1994). The key point is to choose the sources that best fit the case

study and its goals and objectives. Multiple evidence sources are not necessary to have a solid and valid case study (Yin, 1994).

In these six case studies, interviews were the primary source of evidence. Conducting six interviews were a logical way to accomplish the goals and objectives laid out in the case studies. Review of existing documents on PF adoption and uses were used as another source of evidence. These various documents assisted in understanding and built a solid PF knowledge base.

Once the source(s) of evidence have been identified, the data collection process can begin (Yin, 1994). The data collection process should follow three basic guidelines: 1) use multiple sources of evidence, 2) create a database and take notes, and 3) maintain a chain of evidence (Yin, 1994).

Yin points out that it is not essential that a case study have multiple sources of evidence, however using more than one source can greatly strengthen the reliability of the data collected, thereby becoming worthy of further analysis (1994). In the six case studies, evidence was collected using two different sources. The primary source of evidence came from the six systematic interviews with the Ohio farmers who met the selection criteria regarding PF adoption and use mentioned earlier. The second source consisted of existing documents, literature, and data that was collected and reviewed from previous PF studies conducted throughout the Midwest.

The second data collection guideline is to create a database and take notes (Yin, 1994). Yin points out that a database is essential to organize and document all data collected during the case studies. Also, case study note taking can take on different

forms. Notes can be hand written, audio or video recordings, or on a computer disk (Yin, 1994)

The database for these six case studies consisted of note taking and audio recording during each individual case study interview. Careful attention to detail was used during note taking and recording to ensure all data and information could later be analyzed and reviewed. Also, the notes and audio tapes are on file and are accessible for data analysis.

The final guideline to data collection is maintaining a chain of evidence. This increases the reliability of the information collected in the case study (Yin, 1994). Being able to refer back to and present the source of evidence that helped the researcher come to a conclusion is essential in building a strong and valid case study. Maintaining a chain of evidence and accurate documentation through record keeping and organization is crucial.

For these six case studies, a chain of evidence was maintained through record keeping of the time, places, and farmers involved in the case study interviews. This was accomplished by written records, audio taping, and by following a case study questionnaire. Also, the researcher conducting the interviews was able to contact and follow up if clarification was needed concerning a specific question or topic. Also, the same researcher summarized the data collected on all six farmers in the case study to limit bias that would result if different researchers summarized the individual cases.

Yin recognized five components of case study research design: 1) the study's question(s), 2) study's propositions (plan or intention), 3) study's unit(s) of analysis, 4) the logic linking the data to the proposition (plan or intention), and 5) the criteria for interpreting findings (1994, p.20).

The case study's questions are the various why and how questions associated with motivation, adoption, and uses of PF by Ohio farmers as stated in the objectives. The proposition, plan or intention of the study is to explain, understand, and answer the case study questions mentioned above in order to develop an effective survey instrument for use with a larger group of PF adopters to collect data and test hypotheses surrounding PF motivation, adoption, costs, and benefits. The units of analysis are embedded, meaning multiple units of analysis involving PF adoption will be analyzed in each individual farmers case, such as motivational factors behind PF adoption and specific management practices that changed due to PF adoption. The same researcher will conduct the logical linking and interpretation of the results and evidence gathered by using qualitative, narrative descriptions of each individual case study. Then, each individual case summary report can be used to draw cross-case comparisons and conclusions, which will assist in modifying the original theory that farmers are motivated, adopt, use PF, and change management practices for many reasons. Also, a single cross-case report will be written to compare and contrast all six cases as a whole to further assist in theory modification and to help identify new theories that can be tested in a mail out survey. The criteria for interpreting and analyzing the findings are described in the next paragraph.

During analysis, case study author Robert E. Stake refers to the process of transforming observations into statements or claims and explains a process where the topic of the study, the research questions, and the insight of the researcher combine to determine what analytical strategies should be used in achieving aggregation or interpretation (Kennedy and Luzar). Since this study has an exploratory or hypothesis-generating design, the analysis will focus on looking at each case individually to draw

cross-case conclusions regarding similarities and differences between the six farmers. The comparing and contrasting of each case will help build a picture of who a PF adopter and user is. Building tables that summarize specific traits such as acreage, age, and crops grown will help us understand the characteristics of a PF adopter. Other tables can explain what motivates PF adoption and what management changes are being made due to adoption and use of PF. These individual case summaries and the cross-case report will help develop the questions and format that the survey questionnaire should have. Also, the information found through the case study summary reports will assist in revising the theory of why farmers are motivated to adopt PF, and what changes in management practices will occur. This theory revision process allows for the continuous refinement of the theory based on the observed evidence from all the interviews (Kennedy and Luzar). Although an entirely new understanding is seldom reached, refinement of understanding is (Stake). This is what the objectives are, to achieve an understanding of the various why and how questions associated with motivation, adoption, and uses of PFT by Ohio farmers as stated in the objectives. Also, case studies use replication logic, not sampling logic and are generalizable to theoretical propositions, not populations (Yin). As a result researchers using case study methods should focus on “what Yin (1994) refers to as ‘analytic generalization’ when conducting case studies- analytic because this level of generalization is derived from the analysis of the case that is presented as the preferred vantage point” (Hamel, Dufour, and Fortin) (Kennedy and Luzar, page 584). Analyzing and generalizing the information from all the case studies will result in the development of similarities and differences behind motivation, adoption, uses of PF and management practice that have changed as result of PF adoption. From

the analysis and summaries of the case studies, a mail out survey was developed to test the refined hypotheses of this study.

Survey Procedure

A survey instrument was developed to address and test the hypotheses identified in Chapter 1 listed below:

- 1) Individual farmers will adopt those technology components of PF that will provide the greatest expected benefits (return) for their specific farming needs.
- 2) The net benefits of PF will vary directly with the level of variability of farm fields.
- 3) The net benefits of PF will vary directly with farm size
- 4) The net benefits of PF will vary directly with the formal education level of the primary operator.
- 5) The net benefits of PF will increase as the number of precision farming component technologies used increases.
- 6) The primary motivational factor behind adoption of PFT is to increase profits.
- 7) Adoption and use of PFT has significantly changed farmers' management and decision practices.
- 8) Farmers who have adopted and currently use PFT will continue to adopt additional PFT in the future.

The results and conclusions drawn from the information gathered in the six case studies was valuable in the revision of the hypotheses above and in the development of a survey questionnaire (Appendix C). A target group of PF adopters was identified with the help of an OSU extension agent in Ohio. Together, a central Ohio cooperative was approached with the survey instrument and the objectives of the study. The cooperative agreed to jointly participate in the study by providing a list of 156 customers that fit the profile of current adopters of PF. It is important to note that this was not a random

sample. Rather, it is the population of precision farming patrons from one central Ohio cooperative. The purpose of the study was to understand PF adoption motivation, how farmers use their PF system, what system components they have adopted, the perceived benefits and costs related to PF adoption, and changes in management practices. Thus, a random sample of all Ohio farmers would need to be quite large in order to yield as many precision farmers as are available from the cooperative. Also, it is believed that these adopters are likely quite similar to other precision farming patrons of other Ohio Cooperatives and, perhaps, to Ohio precision farmers more broadly. Thus, it is expected that the conclusions drawn in this study will be applicable to a much larger group of Ohio precision farmers.

The unit being analyzed in the survey is the farm business. The survey asked that the primary farm decision maker complete the questionnaire. The farmers contacted were asked to describe, rank, and react to various questions that were designed to test the research hypotheses. Some of these questions dealt with adoption motivation and an evaluation of private costs and benefits associated with PF usage. Other questions dealt with various management practices farmers may have changed as a direct result of PF adoption and use (Appendix C).

The survey was implemented by mail the first week of March 2001. The initial mailing included a joint cover letter from OSU and the cooperative encouraging and explaining the objectives and importance of the survey, the survey instrument, and a postage paid return envelope. One week after the initial survey was sent, a follow-up post card was mailed as a reminder. Two weeks later, all respondents received another survey, return envelope, and a cover letter that reiterated the importance of their response.

The total return response was 52.56% (82 of 156). The sample size was 156 growers who fit our specific criteria. Seventy-nine percent of the respondents were actively farming and completed the questionnaire (65 of 82). Twelve percent of the respondents were no longer farming (10 of 82) and 8.54% percent refused to answer the survey (7 of 82). The numerical rankings, data, and information collected from the returned surveys were analyzed through statistical measures using the Statistical Analysis System (SAS) software. The data and information examined by SAS included: motivational factors, cost factors, benefit factors, and various management practice changes.

CHAPTER 4

INDIVIDUAL CASE STUDY SUMMARIES

This chapter describes the results of the case studies conducted with six Ohio growers who have significant experience with various precision farming technologies. Several tables and appendixes are referred to throughout the summaries to provide further details into each grower's individual case and to compare across the cases. The six adopters of PF were selected based on specific criteria: that the farmer had adopted at least three or more precision farming technologies and had been using PF for at least two years. OSU county Agricultural Extension agents were asked to assist with grower selection and initial grower contact to convince the growers to participate in this case study.

The case study questionnaire is listed in appendix A and the case study data collection forms are listed in appendix B. The data collection protocol was followed by adherence to the case study questionnaire and the case study data collection forms. A single researcher conducted all six interviews to eliminate bias. The interviews were taped for clarity and backup purposes. The researcher who conducted the interviews also wrote each individual case study report summary and the cross-case summary report.

This section is formatted to include a detailed description of each case farm. This is followed by a cross-case summary. Finally, conclusions are drawn from the cross-case comparisons.

Case Study #1: Ted Jones

Background

Ted is a full time farmer with a high school diploma and 2 years of college. He operates and manages a 1,700 acre grain farm, of which 220 acres are owned. All farmland is located in the East Extension District (figure 4). He uses a personal computer to assist in managing information and records. He has been actively farming for 17 years and has an annual gross sale between \$250,001 to \$500,000. Crops grown include 850 acres of corn and 850 acres of soybeans annually. No identity preserved (I.P.) crops are grown or segregated on Ted's farm (table 1).

Before the adoption of any precision farming technologies, Ted purchased a number of services from local retailers including assistance with grain marketing contracts, seed variety and hybrid selection recommendations, soil analysis, and crop scouting for weeds, insects, and other crop problems (table 2). Ted relied upon local services providers to assist him with several management practices before his adoption of precision farming technologies.



Figure 4: OSU Extension Districts

Interviewee	Andy Smith	Jim King	Mike Gate	Ted Jones	Todd Hall	Steve Brown
Age	51	44	55	42	55	20
Family members involved in farm operation	None	Brother	Wife and Son	None	his wife, his son, and his daughter in-law	Father, Mother, and two brothers
Total years interviewee actively farming	18	23	37	17	38	4
Gross sales per year \$ range	\$500,001 to \$1,000,000	\$250,001 to \$500,000	Over \$1,000,000	\$250,001 to \$500,000	\$500,001 to \$1,000,000	Over \$1,000,000
Fulltime or part time farmer	Fulltime	Fulltime	Fulltime	Fulltime	Fulltime	Fulltime and do significant custom application of various inputs
Highest level of education achieved	High school diploma	High school diploma and 1 year of college	High school diploma	High school diploma and 2 years of college	High School diploma	2 year Associates degree
Total acres farmed	2000	1350	3400	1700	2700	2300
Total acres owned	700	1200	1500	220	690	700
Location of farm (OSU Extension district map)	Southwest	South	Northwest	East	Southwest	Southwest

Table 1: Summary of Farming Business and Interviewee Case by Case

(continued)

Table 1: Continued

Interviewee	Andy Smith	Jim King	Mike Gate	Ted Jones	Todd Hall	Steve Brown
Crops grown and acreage	#2 yellow corn 900 acres, soybeans 900, wheat 100	# 2 yellow corn 600 acres, soybeans 600, and wheat 100	High oil corn 1100 acres, #2 yellow corn 400, soybeans 1500, wheat 400	#2 yellow corn 850 acres, soybeans 850 acres	#2 yellow corn 1300 acres and soybeans 1300 acres	#2 yellow corn 1100 acres, soybeans 1100, alfalfa 50, wheat 50
Livestock	NONE	NONE	4000 Hogs	NONE	NONE	NONE
Identity preserved crops grown	Yes: seed soybeans, tofu soybeans, non-GMO soybeans, and GMO soybeans	Yes: non-GMO soybeans and GMO soybeans (in the past grew high oil and waxy corn)	Yes: high oil corn	No	Yes: tofu soybeans, STS soybeans, non-GMO corn and GMO corn	Yes: seed soybeans
Identity preserved grain contracts require PFT	No	No	No	NA	No	No
Own Computer(s) that are used in daily farm operation	Yes	No	Yes	Yes	Yes	Yes

Agricultural Services Purchased from Retailer/Co-op Before Adoption of PFT	Andy S.	Jim K.	Mike G.	Ted J.	Todd H.	Steve B.
Soil sampling	1	4	na	na	na	na
Soil analysis tests	1	3	1	3	1	1
Application of fertilizers and/or lime	1	2	na	na	na	2
Application of herbicides	1	na	na	na	na	na
Application of insecticides	1	1	na	na	na	na
Scouting for weeds	na	na	na	4	2	na
Scouting for insects	na	na	na	5	na	na
Scouting for crop diseases	na	na	na	6	na	na
Hybrid & Variety Seed selection	na	na	na	2	na	na
Marketing grain	na	na	na	1	na	na
Continued education programs & courses in agriculture	na	na	na	na	1	na

Table 2: Agricultural Services Purchased from Retailer/Coop Before Adoption of PFT
Importance rank by grower (1= most important).

Adoption and Motivation

Ted began using precision farming technologies in 1995 with the adoption of a yield monitor, global positioning system (GPS) receiver, and geographic information system (GIS) mapping software. Later, he added soil sampling by management zones based on crop yields in 1997, and infrared photography and a light-bar navigation system in 2000. Ted has had many technical problems and difficulties with the light bar navigation system, but he is certain he will work the “bugs” out. He also has had difficulty scheduling infrared photographs to be taken at appropriate times during the growing season (table 3).

Ted Jones				
PFT Currently Adopted and actively Being Used in Farming Operation and Management	Year adopted	% acres used on	activity done on farm or hired-out	rank
2 to 3 acre soil grid sampling	na	na	na	na
Management zone soil sampling	1997	100%	hire-out	4
GPS VR application of fertilizers (N,P, or K)	na	na	na	na
GPS VR application of lime	na	na	na	na
GPS VR application of liquid manure	na	na	na	na
GPS VR application of herbicides	na	na	na	na
GPS VR planting	na	na	na	na
Yield Monitor	1995	100%	ON	2
GPS Receiver	1995	100%	ON	1
GIS Mapping software	1995	100%	hire-out	3
Infrared aerial photography	2000	50%	hire-out	5
Georeferenced scouting for weeds	na	na	na	na
Field areas elevation measured with lasers and GPS referenced	na	na	na	na
Light-bar navigation system	2000	< 5%	hire-out	6

Table 3. PFT Currently Adopted and Using Importance rank by grower (1= most important).

When asked to identify important motivational factors for precision farming technology adoption, Ted mentioned three factors as the most important (in decreasing order of importance): to increase his profits, to facilitate on-farm experiments, and to decrease overall production risks (table 4).

Motivational Factors	Andy S.	Jim K.	Mike G.	Ted J.	Todd H.	Steve B.
Increase profits/make better management decisions	1	1	2	1	1	1
Increase market value of owned land	na	na	na	4	na	na
Increase ability to compete for leased land	na	na	6	4	6	8
To better understand their field variability (fertility, yield, pH, etc...)	na	4	3	na	3	2
Keep clearer records	4	2	7	na	na	5
To comply with environmental laws or regulations	na	na	1	5	2	7
Decrease risk and overall risk management	2	na	5	3	na	4
To conduct their own on-farm experiments	3	3	na	2	5	3
Stay on top of current technology available to assist in management	na	6	na	na	na	na
Challenge/Try something new	na	na	na	na	3	na
Price was right/fair for P.F.T.	na	5	na	na	na	na
Project a positive leadership position in community	na	na	4	6	na	6
Future use with identity preserved crops	na	na	na	na	4	na

Table 4. Primary Motivational Factors Behind Adoption of PFT
Importance rank by grower (1= most important).

Information and Management Practices

Through the adoption and use of precision farming technologies, Ted has been able to collect several pieces of new information about his farm (table 5). The three most important pieces of information include (in decreasing order of importance), better knowledge and information from which to select hybrids and varieties, identification of management zones based on crop yields rather than uniform soil sampling grids, and detailed soil nutrient levels in each management zone, especially pH.

Ted and his crop consultant have identified soil management zones based on crop yield results to determine where individual soil samples should be taken. His soil samples are taken by a crop consultant and analyzed by an independent lab. The soil sample test results give Ted the unique soil characteristics of each individual management zone. Ted has the soil tested for phosphorus, potassium, calcium, magnesium, organic matter, pH level, and cation exchange capacity (CEC). Also, Ted mentioned that certain management zones are tested for other macro and micronutrients if necessary. The crop consultant that he hires makes the fertilizer recommendations based on the soil sample test results.

Key Information Gained from Entire P.F. System	Andy S.	Jim K.	Mike G.	Ted J.	Todd H.	Steve B.
Precise soil nutrient levels in grids and/or management zones	1	6	4	3	2	3
Precise soil pH levels in grids and/or management zones	na	na	1	3	2	na
Verify using management zones instead of standard soil grid sampling	na	na	na	2	na	na
Selection of crops planted (hybrid & variety selection process)	3	1	6	1	na	4
Crop rotation selection	na	8	na	na	na	na
Crop records	na	na	na	na	na	5
Crop insurance records	na	2	na	na	na	na
Environmental record keeping	na	7	5	6	4	6
Quantified & precise areas of high/low yield variability	2	4	3	na	3	1
Drainage patterns or problem areas	na	5	2	4	1	2
Precise knowledge of weed problem areas	na	na	na	5	5	7
Know what to set grain dryers at to dry grain efficiently	na	3	na	na	na	na
Know where equipment failure may have occurred	na	na	na	7	na	na

Table 5. Key Information Gained from Entire PF System
Importance rank by grower (1= most important).

Ted does not use geo-referenced variable rate application of fertilizers at this time primarily because there is a lack of local providers of this service. He also feels there is a lack of “freedom of options” from the local providers. Ted mentioned that his local agricultural service providers only sell variable rate application of fertilizers in certain “packaged” service agreements and are reluctant to sell him only the individual services he wants. This has led Ted to be mostly dissatisfied with his local agricultural service provider. However, he does plan on using geo-referenced variable rate application of phosphorus, potassium, and lime in the next one to three years.

Ted has not used geo-referenced variable rate application of herbicides or pesticides, but has manually varied the rate of herbicides (Round-Up™). He has not geo-referenced variably applied herbicides or pesticides due to the lack of local providers and the lack of choices from these providers. Ted’s crop consultant makes the herbicide and pesticide recommendations on an as needed basis.

Ted has not used geo-referenced variable rate seeding, but he has manually varied the soybean variety in the same field. His crop consultant makes the hybrid and variety seed recommendations. He has not varied the soybean planting population within the same field.

Before Ted began using precision farming technologies, he used a customary process to determine how much phosphorus fertilizer to apply to his fields. Ted had standard “z” pattern soil samples taken from each field. Each field’s soil sample was analyzed and Tri-state Fertilizer Recommendations (Vitosh et al.) were used to determine a single, uniform rate of phosphorus for each field based on nutrient removal and a yield goal.

After Ted's adoption of several precision farming technologies, phosphorus application has been determined by taking soil samples from each unique soil management zone. Yield results, yield goals, Tri-state Fertilizer Recommendations, and nutrient removal guidelines are used to determine the rate of phosphorus applied. A uniform application rate of phosphorus is still used, however Ted manually varies the rate of phosphorus applications in specific fields when individual soil management zones will benefit from a manually varied application rate. Ted hopes to use geo-referenced variable application of phosphorous, potassium, and lime in the next one to three years.

Since the adoption and use of precision farming technologies, Ted has changed several management practices. Ted's three most important management changes are his hybrid and variety seed selection process, earlier spring planting, and tillage practices (less no-till, more minimum till, and more deep shank tillage) (table 6).

Management Practices that have changed as a result of PFT adoption	Andy S.	Jim K.	Mike G.	Ted J.	Todd H.	Steve B.
Fertilizer, lime or manure application rate	1	1	1	5	na	3
Fertilizer application timing	Na	na	4	na	na	na
Hybrid & variety seed selection	4	2	6	1	3	2
Planting population	Na	na	5	6	na	5
Planting timing	Na	na	na	2	na	na
Planting depth	Na	na	na	4	na	na
Tillage practices	Na	3	3	3	na	4
Use of field scouting	Na	na	na	7	na	na
Field tiling and drainage system	Na	na	2	10	1	1
Pesticide application timing	Na	na	na	8	na	na
Pesticide application rate	Na	na	na	9	na	6
Pesticide product used	Na	na	na	11	na	na
Weed control program	Na	na	na	na	2	na
Management of field borders	Na	na	na	na	na	7
Assisted to verify many of the management practices that they have used in the past and continue to use	2	na	na	na	na	na
Allocation of which fields combine with yield monitor will harvest and collect data from	3	na	na	na	na	na

Table 6. Summary of How PF has Changed Management Practices
Importance rank by grower (1= most important).

Successes, Disappointments, and Problems

The biggest success for Ted has been better overall input management. The use of precision farming technologies has helped Ted make accurate measurement of bushels available to sell so he can market his grain with more confidence and fulfill contracts. Also, he feels that better overall management decisions have been made since adoption of precision farming technologies. These have directly led to higher yields and increased profits.

Ted's biggest disappointment with precision farming technologies has been the lack of technical and customer support for this emerging technology, especially for his GPS receivers. Getting the "bugs" out has been a big challenge for Ted. Overall, he is mostly satisfied with his entire precision farming system.

When Ted has had a problem with his precision farming system, he has relied on the local extension agent, manufacture's customer support line, his crop consultant, local agricultural service provider, and friends for information and help in solving these problems (table 7).

Information sources relied upon when having problems with P.F. system	Andy S.	Jim K.	Mike G.	Ted J.	Todd H.	Steve B.
Manufactures customer support phone number	1	2		2	3	2
Instruction manual	2	1		na	2	5
e-mail	na	na		na	2	na
On-Line web site	4	na		na	na	4
Farm machinery shows	na	6		na	na	na
Manufacture representative coming to farm	3	na		na	na	3
Local Ag. retailer/co-op	na	4		4	na	na
County extension agent	na	5		1	na	na
Hired specialist	na	na		na	4	na
Programming engineers	na	na		na	1	na
Crop consultant	na	na		3	na	na
Friends/fellow farmers	na	3		5	5	na
Themselves (figure out the problem on their own)	na	na		na	na	1

Table 7. Information Sources relied upon when having Problems with PF System Importance rank by grower (1= most important).

Future Goals and Conclusions

Ted's future plans are to continue to use, explore, and adopt additional precision farming technologies. His interests and future plans are in geo-referenced variable applied phosphorous, potassium, and lime, timely infrared photography, hybrid and variety seed changes on-the-go, harvest stand counts on-the-go, and grain test weight measurements on-the-go.

Ted was asked to respond to several statements concerning the effects of precision farming technologies on input use and crop yields. Ted thinks precision farming technologies have reduced his overall fertilizer application. He is uncertain if precision farming technologies have reduced his overall pesticide and herbicide application. Ted believes that precision farming technologies have produced higher farm average yields. He is uncertain if precision farming technologies have decreased yield variation. Lastly, Ted stated that he felt the benefits of precision farming technologies have clearly exceeded the costs.

Overall, Ted sees tremendous value and potential on his farm with precision farming technologies. He also feels that this technology has been instrumental in helping him make better daily management decisions and he is definitely interested in what precision farming technologies may bring in the future.

Case Study #2: Andy Smith

Background

Andy is a fulltime farmer who is in an equal partnership on 4,000 acres of farmland with a friend. His share of the farm is 2,000 acres of grain crops located in the Southwest Extension District (figure 4). Andy and his partner share all farm management duties equally throughout the year. He has been actively farming for 18 years and his gross sales are between \$500,001 and \$1,000,000 annually. He completed a high school education and actively uses a computer to assist in his daily farm management decisions.

His crop acres are divided into 900 acres of number 2 yellow corn, 900 acres of soybeans, and 100 acres of wheat annually. He has grown Tofu soybeans, soybeans for seed, non-GMO soybeans, and Round-up ReadyTM soybeans, all of which have been identity preserved. His Tofu soybeans have been grown under contract and precision farming technology has not yet been needed to secure the contract (table 1).

Prior to the adoption of any precision farming technologies, Andy purchased the following services from local agricultural suppliers: soil sampling, soil analysis, spraying or application of fertilizers, insecticides, and herbicides. Andy mentioned that the unique economic situation at the time determined which of these services were the most important to him (table 2).

Adoption and Motivation

In 1990, Andy began using precision farming technologies with the adoption of management zone sampling on the 2,000 acres. Andy defined the management zones by soil type. He followed this sampling technique by taking 2.5 acre soil samples on about 400 acres in 1998 to check and compare these 2.5 acre soil grid results with the management zone sampling results from 1990. Then in 1999, Andy adopted a yield monitor, global positioning receiver (GPS), geographic information system (GIS) mapping software, and geo-referenced variable application of lime (table 8).

When asked what the primary factors were that motivated him to adopt precision farming technologies, he stated the three most important factors (in decreasing order of importance) were to increase profits, to decrease risk, and to discover and confirm answers to his questions about his farm (table 4).

Information and Management Practices

By Andy's use of precision farming technologies, he has been able to obtain several valuable pieces of information about his farming operation (table 5). Andy felt the most important information was soil nutrient level results, especially the pH levels, in the 2.5 acre grids and in the management zones. He also mentioned he was now able to quantify yield variability in each field and better evaluate crop yields to make better seed and variety selections that performed the best on his farm.

Andy Smith				
PFT Currently Adopted and actively Being Used in Farming Operation and Management	year adopted	%acres used on	activity done on farm or hired-out	rank
2 to 3 acre soil grid sampling	1998	20%	hired-out	1
Management zone soil sampling	1990	100%	hired-out	1
GPS VR application of fertilizers (N,P, or K)	na	na	na	na
GPS VR application of lime	1999	5%	hired-out	2
GPS VR application of liquid manure	na	na	na	na
GPS VR application of herbicides	na	na	na	na
GPS VR planting	na	na	na	na
Yield Monitor	1999	50%	ON	3
GPS Receiver	1999	50%	ON	3
GIS Mapping software	1999	50%	ON	3
Infrared aerial photography	na	na	na	na
Georeferenced scouting for weeds	na	na	na	na
Field areas elevation measured with lasers and GPS referenced	na	na	na	na
Light-bar navigation system	na	na	na	na

Table 8. PFT Currently Adopted and Using Importance rank by grower (1= most important).

A crop consultant currently takes Andy's soil samples and an independent lab conducts the analysis. He tests the soil for nitrogen, phosphorus, potassium, magnesium, calcium, pH level, CEC, and organic matter. These soil test results give Andy detailed and precise information about each individual 2.5 acre grid or management zone. The crop consultant Andy hires makes fertilizer recommendations based on the soil sample test results.

Currently, Andy is only applying lime using geo-referenced variable rate application. The reason that Andy only applies lime using geo-referenced variable application technology is that management zone results from the last ten years only show profit potential for lime due to the extensive pH variability in Andy's fields. However, because the phosphorus and potassium levels in the management zones are fairly consistent and uniform, geo-referenced variable application of these inputs does not appear to make economic sense to Andy.

Andy does not variably apply any herbicides, insecticides, or pesticides using precision farming methods for a number of reasons. The main reason is he does not feel it makes economic sense. He also feels that he does not have significant weed variability to justify variable rate herbicides and he lacks the equipment to geo-reference variably apply these inputs. Andy's crop consultant and various chemical representatives make the pesticide recommendations.

Andy does not use geo-referenced variable seeding of any crop. He feels that there is a lack of solid information to justify variable rate seeding at this time. Also, he feels his farm lacks soil variability, thus he feels variable seeding benefits would not out-

weigh the costs. However, Andy did mention he does **manually** vary his corn seeding population on 100 acres annually.

When the question of how much phosphorus to apply to his fields **before** adoption of precision farming technologies, Andy spoke of taking standard “z” pattern soil samples from each field, following Tri-State Recommendations, and crop removal and yield goal guidelines to determine a single, uniform application rate of phosphorus to each field.

After Andy’s adoption of his current precision farming system, he still follows Tri-State Fertilizer recommendations. He still applies single, uniform rates of phosphorus, but in a few unique situations where soil analysis calls for it, he **manually** applies phosphorus at a variable rate. This does not occur very often since Andy’s soils are generally uniform.

The two most important management practices that Andy has changed as a result of his adoption of precision farming technologies are geo-referenced variable application of lime and the verification and checking of existing management practices (table 6). Also, with the adoption of a combine yield monitor, Andy is able to see which varieties and hybrids are performing the best and worst across his fields. This has changed the way he selects seed for the following years. Another significant change Andy has made since adoption of his precision farming system is he now has soil samples collected in soil type management zones and in 2.5 acre grids.

Successes, Disappointments, and Problems

Andy's biggest success has been that he feels he can verify and confirm that current management practices are acceptable and economically sound on his farm. His precision farming system has given him a way to increase his confidence and verify the management decisions he makes daily. For the most part, he is satisfied with his overall precision farming system.

The biggest disappointment with his precision farming system to date has been the lack of the ability to justify the overall cost of the entire system. He shows positive return with geo-referenced variable application of lime, but negative returns on geographic information system field maps and the yield monitor. The net result continues to be an overall negative return for Andy.

When Andy has problems with his precision farming system, he relies on the manufacturer's customer support line, instruction manuals, a manufacturer representative coming to the farm, and on-line web sites to get answers to solve his problems (table 7).

Future Goals and Conclusions

Andy's future plans include continued adoption and exploration of precision farming technologies. He has interest in light-bar navigation system technology and using precision farming technologies to develop detailed herbicide application maps. He also mentioned that if any new technology shows economic return, he would invest in it.

Andy's responses to several statements concerning the effects of precision farming technologies on input use and crop yields were consistent. Andy does not feel precision farming technologies have reduced overall fertilizer, herbicide, or pesticide applications. He does not feel that precision farming technologies have produced higher farm average yields nor does he feel precision farming technologies have decreased yield variation. Andy also stated that he did not feel that the benefits of precision farming technologies clearly exceed the costs. Andy is mostly satisfied with his local agricultural service provider.

Andy feels that the economic or profit potential of any precision farming system will vary greatly from grower to grower and that the only way to know if precision farming technology will be profitable is for that grower to adopt and use the technology. Only then will the grower have an idea if precision farming technologies are profitable for their farm.

Case Study #3: Mike Gate

Background

Mike and his wife are the exclusive owners of their farming operation, which is organized as a corporation. Their son is an employee, the chief financial officer, and the swine manager. Mike is a full time farmer with a high school diploma who manages the grain and feed mill. Mike's wife is the book and record keeper. Mike has been actively farming for 37 years. The farm is located in the Northwest Extension District (figure 4).

Currently, the annual gross sales are over \$1,000,000 and the farm is 3,400 acres. Mike and his wife own 1,500 acres. The crop acreage includes 1,100 acres of high oil corn, 400 acres of number 2 yellow corn, 1,500 acres of soybeans, and 400 acres of wheat. The farm also includes a 4,000 sow farrow to finish operation. Mike has been segregating and identity preserving his high oil corn which has been grown under contract. Precision farming technology has not been required in his high oil corn contracts to date. He and his family use computers to assist in record keeping and for grain management (table 1).

Prior to adoption of any precision farming technology, Mike only purchased soil sample analysis results from a soil lab in order to have accurate measurements of field nutrient levels. Since Mike only purchased this single service, he has the equipment and capital to be nearly independent from outside service providers. His large economy of scale must have played an important role in becoming so independent. It is clear that Mike has been nearly independent of purchasing outside source services, even before adoption of precision farming technology (table 2).

Adoption and Motivation

Mike began adopting precision farming technologies in 1995 with purchase of a yield monitor, followed by 2-2.5 acre soil grid sampling and geo-referenced variable rate application of lime and potassium in 1996. A local agricultural service provider has variably applied the lime and Mike has done the variable application of potassium application in-house since 1996. Global positioning system (GPS) receivers (1998) are

used on the combine, sprayer, corn planter, 4-wheeler, and liquid manure spreader. Mike has been variably applying liquid manure since 1998. He also began using geographic information system (GIS) mapping software in 1999 to map his field nutrient levels and crop yields. Mike began variably planting corn in 1999. A light-bar navigation system is also used when applying herbicides and other inputs on his farm. He tried infrared aerial photography in 1998, but questioned it's potential and has discontinued the use of this technology. Clearly, Mike has been expanding his use of precision farming technologies over the last several years. He felt grid soil sampling, variable application of fertilizers and yield monitors were the most important technologies adopted so far. Infrared photography has been the least important (table 9).

The three most important motivational factors behind Mike's adoption of precision farming technologies were to better comply with environmental regulations, especially with phosphorus, to increase profits, and to better understand field variability. The least important motivational factor was to keep clearer records for identity preserved crops (table 4).

Mike Gate				
PFT Currently Adopted and actively Being Used in Farming Operation and Management	year adopted	% acres used on	activity done on farm or hired-out	rank
2 to 3 acre soil grid sampling	1996	100%	ON	1
Management zone soil sampling	na	na	na	na
GPS VR application of fertilizers (N,P, or K)	1996	100%	ON	2
GPS VR application of lime	na	na	na	na
GPS VR application of liquid manure	1998	10%	ON	6
GPS VR application of herbicides	na	na	na	na
GPS VR planting	1999	45%	ON	6
Yield Monitor	1995	100%	ON	3
GPS Receiver	1998	100%	ON	4
GIS Mapping software	1999	100%	ON	5
Infrared aerial photography	only 1998	6%	hired-out	7
Georeferenced scouting for weeds	na	na	na	na
Field areas elevation measured with lasers and GPS referenced	na	na	na	na
Light-bar navigation system	na	na	ON	na

Table 9: PFT Currently Adopted and Using Importance rank by grower (1= most important).

Information and Management Practices

Precision farming technologies that Mike currently uses have led to the discovery of many important pieces of information and knowledge (table 5). The three most important were detailed soil pH levels, drainage patterns and problems associated with soil compaction, and quantified, precise areas of yield variability. The least important piece of information gained was the selection of crops planted.

Detailed soil grid sampling is an important part of Mike's precision farming system. The uniform soil grids are 2 to 2.5 acres in size and he has these samples taken by in-house employees. However, an independent lab does the soil test analysis. The soil lab tests for nitrogen, potassium, phosphorus, organic matter, calcium, and magnesium levels. A farm employee makes the fertilizer recommendations for Mike using the Tri-State recommendations as a guideline.

Mike geo-reference applies potassium at variable rates using the farm's own equipment and employees. Lime is also geo-reference applied at variable rates, but a custom application service is used. Mike is not currently using variable rate application of herbicides or pesticides. He feels there is no information or benchmark from which to variably apply these inputs. Organic matter content maybe a start, but Mike still feels uncertain. Mike talks with his chemical representatives and in turn they make the herbicide and pesticide recommendations together.

Currently, Mike does his own geo-referenced, variable rate seeding on about 20% of his corn acres. He has **manually** varied his soybean seeding rate. However, Mike

does not vary the hybrid or variety of seed **within** fields. Seed companies assist Mike in hybrid and variety seed decisions and recommendations.

Before adoption of precision farming technologies, Mike followed the Tri-State fertilizer recommendations and the standard “z” pattern soil sampling method in each field. Then a single, uniform rate of phosphorus fertilizer was applied to each individual field.

Since the adoption of various precision farming technologies, Mike continues to use the Tri-State recommendations for fertilizer decisions. For potassium, Mike has changed to a geo-referenced, variable rate application based on the 2-2.5 acre grid soil test results. However, phosphorus is applied at uniform rates based on the soil test results. Thus, his adoption of precision farming technologies has significantly changed the way he applies potassium, but has not changed his phosphorus application method much.

A more detailed analysis of the management practice changes Mike has made since his adoption of precision farming technologies reveals other significant adjustments. Mike mentioned that fertilizer application rates and adding on to and putting in more field tile as the most important management changes. The least important management change was hybrid and variety seed choice changes (table 6).

Successes, Disappointments, and Problems

Mike’s biggest success from the adoption and use of precision farming technologies has been the personal gratification and satisfaction from becoming

increasingly independent and having the increased confidence in the management decisions he makes each day.

His biggest disappointment from the use of precision farming technologies has been the tremendous learning curve associated with this technology. The software has been very time consuming and difficult to understand because of constant software changes and upgrades.

Future Goals and Conclusions

Mike plans to continue to purchase, adopt, and use new precision farming technologies as they become available. He is especially interested in any future technology that can perform on-the-go soil testing or sampling. He also mentioned he would continue to evaluate current information from his existing precision farming technologies to draw more and more value from it and learn from it.

Mike was asked to respond to several statements concerning the effects of precision farming technologies on input use and crop yields. Mike thinks that precision farming technologies have reduced overall fertilizer application on his farm. However, he was uncertain if precision farming reduced overall pesticide and herbicide application. He stated that precision farming has produced higher farm average yields for him. He also mentioned that precision farming has decreased his yield variation. Mike felt that the benefits of the precision farming system have not exceeded their costs. Mike said that the highest costs of precision farming technologies lie within processing the information gained from using all the various technology tools he has adopted. Mike mentioned that

he felt that OSU extension personnel lack the numbers and ability to support and work with precision farming technologies. He feels that farmers like him need more support and assistance with this technology from local extension agents.

When evaluating the local agricultural service provider, Mike mentioned the importance of the provider being a leader and on the cutting edge of precision farming technology. He was mostly satisfied with his local service provider.

Overall, Mike feels that precision farming technologies have been instrumental in helping him determine various operating costs on his farm. He feels a thorough understanding of his costs is crucial to his success and profitability in the future. This knowledge has helped him in countless management decisions. Mike also stated he was satisfied with his overall precision farming system.

Case Study #4: Jim King

Background

King Farms consists of two owner operators, Jim and his brother Dave. They split most of the daily management responsibilities evenly. Jim is a fulltime farmer and has been actively farming for 23 years. Jim achieved a high school diploma and finished 1 year of college. The farm consists of 1,350 acres, 1,200 of which are owned by King Farms. Jim rents or leases an additional 150 acres. The farm is located in the Southern Extension District (figure 4). It is a grain farm that grows corn, soybeans, and wheat. Crop acreage is split, 600 acres of corn, 600 acres soybeans, and 100 acres of wheat. Jim

does not currently raise any livestock on the farm and gross sales last year were between \$250,001 and \$500,000 (table 1).

Jim began identity preserving (IP) his soybeans this past year by keeping his non-genetically modified and his genetically modified soybeans separate from each other. He feels there may be a marketing opportunity or niche for IP soybeans. Jim has grown other crops in the past that have been identity preserved, including high oil corn and waxy corn, but the market premiums are not as attractive now as they once were so these specialty crops have not been grown for several years.

Before adopting any precision farming technologies, Jim was purchasing several agricultural services from local retailers. He relied on local retailers to apply insecticides and dry fertilizers, gather soil samples, and perform soil test analysis (table 2). Jim also mentioned that he is currently mostly satisfied with the service of his local agricultural service provider.

Jim is currently using many precision farming technologies on the farm, several of which have been used since 1994. He began using precision farming in 1994 by taking 2.7 acre grid soil samples and having infrared aerial photographs taken of about 300 acres. In 1995, Jim began utilizing a yield monitor, a GPS receiver, and GIS field mapping software. Also, Jim adopted geo-referenced variable application of potassium and phosphorus in 1997 and had about 100 acres geo-referenced by elevation for drainage pattern purposes. According to Jim, the yield monitor is the most important and infrared photography the least important technology adopted to date. Most of these precision farming technologies are used on all 1,350 acres (table 10).

Jim King				
PFT Currently Adopted and actively Being Used in Farming Operation and Management	year adopted	% acres used on	activity done on farm or hired-out	rank
2 to 3 acre soil grid sampling	1994	100%	hired-out	4
Management zone soil sampling	na	na	na	na
GPS VR application of fertilizers (N,P, or K)	1997	15%	hired-out	5
GPS VR application of lime	na	na	na	na
GPS VR application of liquid manure	na	na	na	na
GPS VR application of herbicides	na	na	na	na
GPS VR planting	na	na	na	na
Yield Monitor	1995	100%	ON	1
GPS Receiver	1995	100%	ON	2
GIS Mapping software	1995	100%	hired-out	3
Infrared aerial photography	1994	15-20%	hired-out	7
Georeferenced scouting for weeds	na	na	na	na
Field areas elevation measured with lasers and GPS referenced	1998	7%	hired-out	6
Light-bar navigation system	na	na	na	na

Table 10: PFT Currently Adopted and Using Importance rank by grower (1= most important).

The three primary factors that motivated Jim to adopt and use PFT were to make better management decisions, to keep clear and precise records, and to conduct on farm experiments, especially with corn hybrid selection (table 4).

Information and Management Practices

Jim has been able to collect and analyze many new pieces of information about his farm since adopting various precision farming technologies. The most important pieces of information he has gathered are corn hybrid performance data, crop yield records for insurance purposes, and the moisture of harvested corn for precise grain dryer settings (table 5).

Jim uses 2.7 acre soil sample grids. The samples have been collected by local service retailers, county agents, and himself. The soil analysis is done by an independent lab which tests for phosphorus, potassium, magnesium, calcium, pH, organic matter, and CEC. The fertilizer recommendations are then made by local service retailers and reviewed and approved by Jim.

Jim has had geo-referenced variable application of phosphorus and potassium done since 1997 by his local agricultural service provider. Also, Jim has been applying lime to fields by **manually** varying the rate where his grid soil test results call for different application rates.

Jim has not variably applied any herbicides or pesticides on his fields to date. He feels that with the current herbicides and pesticides, he sees no value or need to vary the

rate of these inputs at this time. Jim, the local service retailer, and the chemical representatives make the herbicide and pesticide recommendations together.

Variable rate seeding is not currently being used on King Farms. Jim has reviewed data and he sees little value in using this seeding technique on his farm at this time. He feels that the benefits would not cover the costs. Jim does not vary hybrids or varieties within fields nor does he manually vary the populations within fields. Jim decides which hybrids and varieties to plant with information from OSU yield trials and from seed company representatives.

Before Jim adopted any precision farming technologies, he used a standard, frequently used process to determine how much phosphorus fertilizer to apply to his fields. Jim had “z” pattern soil samples taken from each field and Tri-State crop removal and yield goal information was used to determine the single, uniform rate of phosphorus that would be applied to each field.

After adoption of several precision farming technologies, Jim has determined how much phosphorus to apply to his fields by taking 2.7 acre grid soil samples of fields, looking at the grid soil test results, and reviewing geo-referenced yield map history. Then he has a local service provider geo-reference variably apply phosphorus where it is necessary (usually about 200 acres annually) and then single rate applies phosphorus on the remaining acres.

Precision farming technologies have changed a few of Jim’s management practices. The three most important changes are the fertilization application method of phosphorus, potassium, and lime, the selection of hybrids and seed varieties, and choice of tillage practices (more no-till soybeans) (table 6).

Successes, Disappointments, and Problems

The biggest success that Jim has had with precision farming technologies deals with precise crop yield maps. He mentioned that the detailed yield map results generated by the global information system software are extremely valuable to him. He can review and analyze yields and strives to make better hybrid and variety selections in the future based on this map information.

His biggest disappointment has been the extreme variability in the results of grid soil samples taken 3 years ago compared to the grid soil sample results taken recently. He is not sure why he is seeing so much nutrient level variability in these 2.7 acre soil grids. He mentioned that he may start taking geo-referenced soil samples by some type of management zone method, like yields or soil type, and stop using the 2.7 acre grid method.

When Jim has a problem with his precision farming system he relies on several information sources to help solve the problem. His most important sources to solve these problems are the instruction manuals, manufacture's customer support phone line, and friends and fellow farmers who are knowledgeable with the technology (table 7).

Future Goals and Conclusions

Jim plans to continue to use and adopt additional precision farming technologies as new components are developed. He is interested in light-bar navigation system technology, possible geo-referenced variable application of ammonia, geo-referenced variable planting of soybeans, and soil conductivity measuring tools.

Jim responded to several statements about the effects of precision farming technologies on input use and crop yields. He stated that he did not think precision farming technologies have reduced his overall fertilizer, herbicide or pesticide applications. He is uncertain if precision farming technologies have produced higher farm average yields. He did not think that precision farming technologies have decreased yield variation. However, Jim stated that the benefits of precision farming technologies have clearly exceeded the costs. He said that the data and information he has collected on his farm by using precision farming technologies has been instrumental in making better management decisions. Jim said he was currently satisfied with his overall precision farming system.

Case Study #5: Todd Hall

Background

Todd has been actively farming for 38 years. The farm is located in the Southwest Extension District (figure 4). The farm has \$500,001 to 1,000,000 gross sales annually. Todd achieved his high school diploma and is a strong believer and participant in short course continuing education programs. Todd, and his son Rob, share the daily responsibilities of operation and management on their grain farm. His wife and his son's wife also take an active role in the farm business. The wives are involved in geographic information system (GIS) field mapping, maintaining yield records, accounting records, and miscellaneous activities on the grain farm. All four family members are full time farmers. The family farm consists of 2,700 grain crop acres of which Todd owns 690

(table 1). The family actively uses three computers to assist in the management, operation, and record keeping on the farm.

Grain crops grown are number 2 non-genetically modified yellow corn, STS soybeans, Tofu soybeans, and number 2 genetically modified yellow corn. Todd identity preserves all four of these crops by segregating them into separate grain storage bins. The STS and Tofu soybeans are sold under contract and precision farming technologies have not been required by the contracts.

Before the adoption of any precision farming technologies, Todd only purchased a few services from local agricultural service providers. He purchased soil sample analysis by independent labs and weed scouting (table 2). For many years Todd's farm has operated and done many of the daily tasks with their own machinery and labor. Todd has been fairly independent in the past.

Adoption and Motivation

Todd began using precision farming technologies in 1995 with the adoption of a yield monitor, two GPS receivers, and geographic information system (GIS) field mapping software. He later added 3 acre grid soil sampling in 1996 and a light-bar navigation system in 1998 (table 11).

Todd Hall				
PFT Currently Adopted and actively Being Used in Farming Operation and Management	year adopted	% acres used on	activity done on farm or hired-out	rank
2 to 3 acre soil grid sampling	1996	100%	ON	3
Management zone soil sampling	na	na	na	na
GPS VR application of fertilizers (N,P, or K)	na	na	na	na
GPS VR application of lime	na	na	na	na
GPS VR application of liquid manure	na	na	na	na
GPS VR application of herbicides	na	na	na	na
GPS VR planting	na	na	na	na
Yield Monitor	1995	100%	ON	1
GPS Receiver	1995	100%	ON	3
GIS Mapping software	1995	100%	ON	2
Infrared aerial photography	na	na	na	na
Georeferenced scouting for weeds	na	na	na	na
Field areas elevation measured with lasers and GPS referenced	na	na	na	na
Light-bar navigation system	1998	100%	ON	4

Table 11: PFT Currently Adopted and Using Importance rank by grower (1= most important).

Todd has been **manually** varying the rate of application of phosphorus, potassium, and lime since 1996 on approximately 270 acres and plans to **geo-reference** variably apply phosphorus, potassium, and lime in the spring of 2001. Todd also plans on doing some geo-referenced scouting for insects, weeds, and other crop diseases in 2001. The two GPS receivers are used on a 4-wheeler to take geo-referenced soil samples. The receivers are also used on the combine, sprayer, and spreader. Todd has been using precision farming technologies for many years and has significant experience with it.

Several motivational factors drove the decision to adopt precision farming technologies. The primary factors that motivated Todd to adopt were to increase profits, better comply with environmental regulations, understand field yield variability, and the challenge to try something new (table 4).

Information and Management Practices

Todd has been able to collect several pieces of information over the years with precision farming technologies. The most important pieces of information that Todd has collected were better knowledge of field drainage patterns and problems, detailed soil nutrient levels, especially pH, and quantified maps of yield variability (table 5).

Todd and Rob collect all of the 3 acre grid soil samples on their farm every three to four years. An independent soil lab analyzes the samples for nitrogen, phosphorus, potassium, calcium, magnesium, pH, organic matter and CEC. Todd makes the fertilizer recommendations based on the soil lab nutrient level results and Tri-State fertilization guidelines.

Todd does not currently use geo-referenced variable rate application of fertilizers, but he does **manually** vary the application of phosphorus, potassium, and lime. Costs and lack of equipment have been the reasons why Todd does not geo-reference variably apply these inputs. However, he does plan in the near future to try geo-reference variable application of phosphorus and potassium. Todd has been doing all the spreading of fertilizers with their own equipment and rarely hires outside providers to do this.

Todd does not variably apply herbicides or pesticides. He feels that more information about this topic is needed and that he lacks the equipment to do this. Chemical representatives and Todd make the herbicide, insecticide, and any other pesticide recommendations when necessary.

Currently, Todd is not geo-reference variably planting any seeds. He feels that on his fields this technology would not be profitable. In Todd's opinion, the information he has seen to date shows little to no advantage with geo-referenced variable planting in his area of the state. Todd only **manually** varies seeding populations within fields. He makes hybrid and variety seed recommendations based on plot records and local performance information. Todd and Rob do all the planting themselves.

Before Todd adopted any precision farming technologies, he determined how much phosphorus fertilizer to apply to his fields by using Tri-State recommendations based on yield goals and crop removal guidelines. Soil samples were taken in a "z" pattern in each field and once the soil nutrient levels were satisfactory according to the soil test results, only crop removal amounts of nitrogen, phosphorus, and potassium have been applied.

After Todd's adoption of several precision farming technologies, he still follows the principal of only applying the amount of nutrient that the crop removes and he still uses the Tri-State nutrient recommendations as guidelines. However, he takes many more soil samples using a 3 acre grid size and he uses historical global information system (GIS) yield maps to further adjust fertilization amounts according to crop yields. He separates his GIS based yield maps into high, medium, and low yield areas to fine-tune fertilization amounts.

Precision farming technologies have changed a few of Todd's management practices. Todd has added and put in new drainage tiling and he also changed his strategy behind his weed control program by paying close attention to the modes of action that his herbicides use to eliminate weeds. Todd is now more aware of the severe yield losses that can occur due to various weed pressure levels. The detailed geographic information system yield maps have been very valuable in determining which hybrids and varieties should be planted in each field (table 6).

Successes, Disappointments, and Problems

The biggest success for Todd has been his increased knowledge and awareness of the "details", like variability in soil pH levels, crop yields, weed pressure, and drainage patterns from field to field. Also, he feels he has a better understanding of his soils types and fertility relationships. There has been an overall gain of agronomic information that has assisted him in making better management decisions.

Todd's single biggest disappointment with precision farming technologies has been lack of affordable and compatible software. As the technology changes and is updated, Todd feels that there are too many problems with the software and computers due to incompatibility issues. He would like to see all major manufactures find a common software language and system to eliminate many of the incompatibility issues. Also, Todd mentioned that better GIS software programs are needed to integrate and manage all the detailed information he collects. Finally, he would like GPS receivers to be designed to be more easily removable, to facilitate their use on different machinery.

When Todd has a problem with his precision farming system, he relies on several sources to help him find a solution (table 7). He makes direct phone calls to the program engineers who developed the technology. He also reviews the instruction manuals and will call the manufacture's customer support line. If it is not an emergency, he will e-mail the company or hire a specialist to fix it in a few days.

Future Goals and Conclusions

Todd plans to continue to adopt and use precision farming technologies over the next three years. He is interested in geo-referenced variable application of dry and liquid nitrogen or anhydrous ammonia. He is also curious about new technology dealing with soil conductivity and geo-referenced variable application of pre-emergent herbicides.

Todd responded to several statements about the effects of precision farming technologies on input use and crop yields. Todd feels that precision farming technologies have not reduced overall fertilizer, herbicide, or pesticide application. He feels

application amounts of these inputs are about the same as before he adopted any precision farming technologies. He stated that precision farming technologies have produced higher farm average yields and that precision farming technologies have decreased yield variation. Lastly, Todd felt that the benefits of precision farming technologies have not clearly exceeded the costs.

Todd is indifferent about his local agricultural service provider because they rarely call upon these retailers for assistance. Their family farming operation is fairly self sufficient because they own and have most of the necessary labor and equipment themselves.

Overall, Todd is mostly satisfied with his current precision farming system. He believes that precision farming technology is valuable and important in his operation and it helps him see the results of his management decisions.

Case Study #6: Steve Brown

Background

Steve is a fulltime farmer who has been actively farming for four years. He has an associate's degree and is going on to get his bachelor's. He farms with his Dad, Mom, and his two brothers. His Dad and Mom are the two shareholders of the entire farm and gross annual sales last year were over \$1,000,000. The grain farm totals 2,300 acres and the family owns 700 of those acres. The acreage is divided into 1,100 acres of number 2 yellow corn, 1,100 in soybeans, 50 in alfalfa, and 50 in wheat. The only identity

preserved crop grown is soybeans for seed, which is under contract (table 1). The contract does not require the Brown's to use any type of precision farming technology. The entire farm is located in the Southwest Extension District (figure 4). Also, the family uses two computers to assist in the farming operation. The family farm does supply seeds and herbicides to other local farmers in the area. They also custom spray and spread inputs and are a basic provider of retail agricultural supplies and services. His Dad is the general manager and his Mom is the financial bookkeeper. He and his two brothers assist in daily operations of the farm and assist with the retail agricultural services they provide to other local growers.

Before the adoption of any precision farming technologies, Steve's family farm purchased only a few services from an outside agricultural service provider. They purchased soil analysis and the application of lime (table 2). The family owns much of their equipment and is largely independent of service providers.

Adoption and Motivation

Currently, the farm uses several precision farming technologies (table 12). The adoption began in 1994 with a yield monitor. In 1995, four global positioning receivers, geographic information system mapping software, and a 2.5 acre soil grid sampling technique were added. Geo-referenced variable application of fertilizers began in 1996 and geo-referenced variable planting of soybeans followed in 1998.

Steve Brown				
PFT Currently Adopted and actively Being Used in Farming Operation and Management	year adopted	%acres used on	activity done on farm or hired-out	rank
2 to 3 acre soil grid sampling	1995	100%	ON	4
Management zone soil sampling	na	na	na	na
GPS VR application of fertilizers (N,P, or K)	1996	100%	ON	5
GPS VR application of lime	na	na	na	na
GPS VR application of liquid manure	na	na	na	na
GPS VR application of herbicides	1998	50%	ON	8
GPS VR planting	1998	50%	ON	6
Yield Monitor	1994	100%	ON	1
GPS Receiver	1995	100%	ON	2
GIS Mapping software	1995	100%	ON	3
Infrared aerial photography	na	na	na	na
Georeferenced scouting for weeds	2000	10%	ON	9
Field areas elevation measured with lasers and GPS referenced	na	na	na	na
Light-bar navigation system	1999	100%	ON	7

Table 12: PFT Currently Adopted and Using Importance rank by grower (1= most important).

Further adoption included geo-referenced variable application of herbicides in 1998 and a light-bar navigation system in 1999. Finally, geo-referenced weed scouting was adopted in 2000. They have used a soil doctor for soil electric conductivity in the past, but have since decided to abandon this tool. They decided it was not adding value to their bottom line. They use the global positioning receivers on the sprayers, fertilizer spreaders, combine, soybean drill, pickup truck, and the 28% nitrogen injector. All these adopted precision farming technologies are used on all 2,300 acres.

The three most important factors that motivated the family to adopt these various precision farming technologies were (in decreasing order of importance) to increase profits, to better understand their field variability, and to conduct their own on-farm experiments. The least important factor was to increase their ability to compete for leased land (table 4).

Information and Management Practices

Steve has been able to gather many new pieces of information and data from the use of these precision farming technologies (table 5). The three most important pieces of information gained from the adoption of precision farming technologies are (in decreasing order of importance) quantified yield variability maps, drainage patterns or problems, and detailed soil nutrient grid maps. Knowledge of weed problem areas is the least important piece of information gained.

Steve's family farm has been using uniform 2.5 acre soil sample grids since 1995. However, Steve felt that they might go to management zones based on yield maps within the next two years. He thinks management zones based on crop yields might be more practical than just standard 2.5 acre grids. Steve does about 90% of the soil sampling and his brothers do the remaining 10%. They use an independent soil lab for soil analysis information. Nitrogen, phosphorus, potassium, calcium, and magnesium are all tested. Also, organic matter, pH, and CEC are measured. On alfalfa fields, Boron is measured in the soil lab analysis. His Dad, who uses Tri-State fertilizer recommendations as a guideline, makes the fertilizer recommendations.

Steve stated that they currently geo-reference variably apply liquid nitrogen, dry phosphorous, and liquid and dry potassium themselves. They hire a neighbor to geo-reference variably apply lime on their fields.

The Brown farm also geo-reference variably applies herbicides themselves, based on organic matter measurements from their soil analysis. They currently only geo-reference variable apply pre-emergent herbicides such as Dual, Bicep, Attrex, and Princep. Employees of Brown farms apply all herbicides and pesticides. Outside agricultural service providers are rarely used for these input applications. Steve's Dad, his brothers, and chemical representatives make these herbicide recommendations.

Steve does use geo-referenced variable rate seeding of soybeans. They do not vary the variety within a field, but they do vary the soybean population within fields. His Dad and two brothers make the hybrid and variety seed recommendations and all geo-referenced variable rate soybean planting is done by employees of Brown farms.

Before the adoption of any precision farming technologies, Steve and his Dad followed Tri-State fertilizer recommendations to determine how much phosphorous fertilizer to apply to fields. Soil samples were taken from 20-acre size grids and analyzed by a soil lab. Then phosphorous was applied by **manually** varying the rate of phosphorous according to the soil test results in each 20-acre grid. This method only **manually** varied the rate of phosphorus.

After the adoption of several precision farming technologies, Steve stated they now take 2.5 acre grid soil samples and geo-reference variably apply phosphorus. They also geo-reference variably apply nitrogen, potassium, and lime according to the soil test results and Tri-State fertilizer recommendations.

The adoption of all these precision farming technologies has led to several farm management changes (table 6). Steve mentioned the three most important changes (in decreasing importance) are an increase in field tiling and drainage system management, the hybrid and variety seed selection process, and fertilizer and lime application rates. The least important management change is field edges and boarder management.

Successes, Disappointments, and Problems

The biggest success in Steve's opinion has been the precise and detailed GIS yield maps, which help answer questions and assist in making better management decisions. Steve stated he is able to see where yields change within fields and look at fertilizer, pH, and soil type map overlays to try to understand why the variability may be occurring.

This analysis can provide ideas that may help find solutions to site-specific yield variability.

The biggest disappointment for Steve has been the overall lack of technical support on the precision farming equipment itself. He feels that the technology is not as user-friendly as it could be and would like to see improvements made in this area.

When Steve has a problem with the precision farming system, he relies on his own knowledge and skills to solve the problem, the manufacturers customer support line, and manufacture representatives to solve it (table 7).

Future Goals and Conclusions

Steve plans to continue to adopt and purchase additional precision farming technologies as they become available. He is interested in GPS satellite imagery and would be very interested in a technology that could measure soil nutrient levels on the go. He is excited about the opportunities that precision farming technologies will bring to the farm in the future.

Steve responded to several statements concerning the effects of precision farming technologies on input use and crop yields. Steve felt uncertain if precision farming technologies have reduced overall fertilizer application. However, Steve did feel that precision farming technologies have reduced overall pesticide and herbicide application. Steve stated that precision farming technologies have produced higher farm average yields and that precision farming technologies have decreased yield variation. Steve

mentioned that he was uncertain if the benefits of precision farming technologies clearly exceeded the costs.

Overall, Steve is mostly satisfied with their overall precision farming system. He said that precision farming technologies provide precise and detailed information and data. He challenges himself by asking “why” the data looks the way it does and tries to develop an understanding to find solutions to questions and problems. Also, Steve mentioned he is indifferent with his local retail agricultural service provider since they rarely use their services at this time.

Cross-Case Summary

The goal of these case studies was to get a detailed look at how growers who have adopted precision farming technologies are using it to manage, set goals, and make decisions on their respective farms. The case studies help paint a picture of the adoption, motivation, uses, and management practices of growers in Ohio who are actively involved in using precision farming technology. Through these in-depth case study interviews, many similarities and differences have been discovered (tables 1-12).

Background

A look at the participants’ personal and farm descriptive information and nature of their farming business reveals several similarities and differences between them (table 1). All the growers are fulltime farmers who have achieved a high school diploma. Three

have gone on to college, with only one achieving an associate's degree. However, all of the growers mentioned the importance of continuing education, either through short course work or through self-study. All the growers have demonstrated knowledge of and an ability to use precision farming technologies in support of farm management decisions.

The participants have been actively farming for a range of 4 to 38 years. The participant with the shortest term in farming is a young partner in a family farming business that has been in operation for many years. Total gross sales in 2000 ranged from \$250,001 to over \$1,000,000, suggesting that these farms are significantly larger than the typical Ohio farm. All six are grain farmers, although one grower also has a large livestock enterprise. Acres farmed in the year 2000 ranged from 1,350 to 3,400, which is well above the average farm size of 206 acres in Ohio (Ohio Census of Agriculture, 1997). The percentage of land farmed that is actually owned by the growers ranged from 12.9% to 88.9%. Five of the six growers own and actively use at least one personal computer in their daily agribusiness operation. The single grower that does not own a personal computer has a local service provider create his GIS yield and fertilizer maps for him.

Five of the six growers had at least one other partner or owner actively taking a role in the business. Of the five who had at least one other partner or owner, four had family members as their other partner or owner. The fifth grower had a fellow farmer who was not an immediate family member as his partner. Only one grower was the sole owner of his farming business. It is obvious that family members are still heavily involved in the operation of these farms. In the cases where more than one owner or

partner is involved with the business, the responsibilities are split up into different categories to balance the workload and to allow individuals to focus on one or two areas of the business. For example, spouses generally took on the record and financial book keeping responsibilities.

Crops grown consist primarily of number 2 yellow corn and soybeans, which are grown on all six farms and make up nearly all the acres of crops grown. Other crops grown include wheat and alfalfa, but in much smaller acreage. Five of the six farms are growing some type of crop that is identity preserved (IP) or segregated. Identity preserved crops included high oil corn, soybeans for seed, Tofu food grade soybeans, and STS soybeans. Also, three of the five growers are segregating their non-genetically modified crops from their genetically modified crops. Examples of genetically modified crops that have been identity preserved by these three growers are Roundup Ready™ soybeans and Liberty Link™ corn. All five of the farmers growing identity preserved crops use a contract to sell these in the market. None of these five farmers were required in their grain marketing contracts to use precision farming technology in any way.

Before adoption of any precision farming technology, all six growers were purchasing soil analysis from outside source soil labs. However, only a few other agricultural services were purchased before adoption. These few purchased services were usually the spreading or spraying of fertilizers or herbicides or field scouting for weeds or insects. Only two growers purchase the service of spreading or spraying of herbicides or fertilizers from outside providers. The other four growers did their own spreading or spraying of herbicides or fertilizers. For the most part, these six farmers were mostly

independent and did not purchase very many services from outside service providers **before** their adoption of precision farming technologies (table 2).

Adoption and Motivation

For this case study, all of the growers were required to currently be using at least three or more precision farming technologies. Five growers have been using at least one precision farming technology since 1995 and four had been using two or more precision farming technologies since 1995. The four most commonly used precision farming technologies in this case study were yield monitors, GPS receivers, GIS maps and software, and global positioned grid or zone management soil sampling. All six growers are currently using all four of these precision farming technologies on nearly all the acres they actively farm. The growers mentioned a common theme that they feel they will be able to make better management decisions as they accumulate more and more years of data and information through their precision farming system. They feel that learning from these detailed records, field maps, and data over time will help them make better management related decisions in the future.

Four growers currently use variable application of fertilizers, lime or herbicides using GPS technology. Of the two growers not currently using this technology, one plans to adopt variable application of these inputs within the next 3 months and the other grower plans to adopt within the next one to three years. Only two growers are planting seeds using variable rate global positioning technology. One is variably planting soybeans and the other is variably planting corn. Only one of the six growers is variably

applying herbicides. The herbicide variable rate is based on organic matter soil tests for the pre-emergent control of weeds in corn fields.

Four growers are exclusively using a uniform grid size method to collect global positioned soil samples. The soil sample grid sizes range from 2 to 3 acres. One grower is using both soil management zones, based on soil type, and the uniform grid size method to collect global positioned soil samples. Only one grower collects global positioned soil samples by using management zones based on yield map results.

The other precision farming technologies that are currently being used by three or less growers are light-bar navigation systems for spraying and spreading reference, infrared aerial photography, variable application of liquid manure, and global positioned elevation contour maps to get a detailed understanding of drainage patterns.

Understanding the reasons and motivational factors behind the growers' adoption of precision farming technologies is an important goal of this case study. The most common motivational factor of adoption was to increase profits. All six growers mentioned increase profits as their first or second most important reason for adoption and use of precision farming technology. All six mentioned a common motivational factor associated with the concept that precision farming technology would give them more precise and detailed information on a field by field basis that would enable them to make better management decisions over time. They felt better management decisions would lead to increased profits. Other motivational factors mentioned were to increase their ability to compete for leased land and to keep more detailed and accurate records (table 4).

Information Gained

A common theme was that knowledge gained from use of the system was an important benefit. Specifically, these six farmers identified knowledge and awareness of detailed and precise crop yields as the most important item of information gained through the use of their precision farming system (table 5).

Yield maps help these growers see the highest and lowest yielding areas within fields and the degree of yield variability across the field. This, combined with other PF data and personal observations, allows them to develop hypotheses for why the variability occurred. Thus, management decisions are changed based on this detailed information to try to correct or minimize the problem in the future. Other important pieces of information gained using precision farming technologies were detailed maps of soil nutrient levels, especially pH levels, and the knowledge of drainage problems and or patterns. Although increased environmental record keeping is mentioned by nearly all the growers, they did not rank it very high. These growers felt they already had an accurate system in place to keep excellent environmental records. Each grower gained various pieces of important information and the ranking of this information varied greatly from grower to grower.

Management Practices

Soil sampling techniques used by these growers are either based on management zones or uniform grid (2 to 3 acres) size. One farmer used both techniques. All the

growers use an outside hired soil lab to perform the soil analysis. The common nutrient and soil measures these growers have the labs test for are nitrogen, potassium, phosphorus, magnesium, calcium, CEC, organic matter, and pH. The growers all mentioned that they would do micronutrient testing if it was a potential solution to a problem they were having, but normally they do not test for micronutrients. Most of the growers follow Tri-State fertilizer recommendations and consult with other partners in their operation or their crop consultant to ensure they make the right management decisions with regards to fertilizer applications.

Four of the growers variably apply fertilizers and or lime using GPS. Fertilizers variably applied include nitrogen, potassium, phosphorus, and liquid manure. Lime is also variably applied. Two of the four growers are variably applying these inputs themselves with their own equipment. The other two are hiring an outside service provider to variably apply these inputs for them. One of the growers not currently using variably applied fertilizers or lime mentioned their lack of equipment and high costs to variable apply as reasons for not adopting. However, they plan on trying variable application of potassium and phosphorus in the next 6 months to discover if it is worth the cost. The other grower not variably applying fertilizers mentioned the lack of local providers and freedom of choice as reasons for not adopting. He must purchase a “packaged” deal of variable rate services from the local service providers. Due to this “packaging”, he is unable to purchase the individual services he really wants.

A lack of documented information and economic evidence are the main reasons five of the growers do not currently variably apply pesticides. Also, one grower mentioned the lack of a benchmark to guide the variable rates of pesticides. Only one

grower is variably applying pesticides and he does this himself. His program consists of variably applying pre-emergent herbicides to cornfields using soil organic matter as a benchmark from which to vary pesticide rates. These growers made most pesticide recommendations with assistance from chemical company representatives, crop consultants, local cooperatives, and retail service providers.

Only two growers are using variable rate seed planting using global positioning systems. One grower is using this variable rate seeding technology with soybeans only and the other is using it with corn only. Both do the variable rate planting themselves with their own variable rate planters. The other four growers that are not currently using this technology stated that there is a lack of information that shows the overall benefits of the technology. Also, the growers felt variable rate seeding using GPS would not be profitable on their individual farms. However, four of the growers mentioned varying the seeding population within their fields by **manually** making adjustments to their equipment as they planted their crops. The six growers mentioned reviewing their own farm yield results along with local and state yield results to make their hybrid and variety seed decisions. Also, talking with seed company representatives and consulting with their farming partners helped them make seed choices.

Since the growers in this case study own much of their agricultural equipment, they are mostly independent from local agricultural service providers. Only four are purchasing services from local providers on a regular basis. Three of the four purchasing outside services are mostly satisfied with the provider they conduct business with (score of 2 on a scale of 5 where 1 is very satisfied). One grower is mostly dissatisfied with his local service provider due primarily to the lack of freedom of choices.

The Changing of Management Practices

Before the adoption of any precision farming technologies, the growers in this case followed standard “z” pattern soil sampling in each field. Several random samples were taken in each field and a uniform fertilizer application rate was used nearly all the time. One grower stated he would divide some of his fields up into 20 acre grids and take individual samples from the areas. Then he would manually vary the rate of a particular fertilizer in certain 20 acre areas if he felt the soil analysis and Tri-State recommendations called for it.

After adoption of precision farming technologies, the growers have changed to either a globally positioned **grid** soil sample or a globally positioned **management zone** soil sample to “micromanage” each grid or management zone according to that area's unique traits. Four of the growers apply various nutrients and or lime to these fields using GPS-based variable rate technology. All six growers use the detailed GPS and GIS soil analysis maps to make better, more informed, management decisions. The use of precision farming technologies has significantly changed the soil sampling process of these six growers.

Other management practices that have been changed as a direct result of the adoption and use of precision farming technologies vary significantly from grower to grower (table 6). The number of management changes made range from 3 to 11. Three growers identified making more tiling management decisions, either repairing, adding

onto, or installing more tile, as the number one or number two most important management change. Another common management practice change has been the hybrid and variety seed selection process. The growers feel that the crop yield maps and soil maps provide better information to make their seed selection decisions. Also, fertilizer and lime application rate management has changed. The detailed soil sample maps have led some of the growers to variably applying nutrients and lime to specific areas. This has been a significant management change for the four growers who are currently applying fertilizers and lime variably using precision farming technologies. Three of these four growers ranked fertilizer or lime application rate as their most important management change from the adoption and use of precision farming technologies. The other grower in this group of four, ranked fertilizer or lime application rate as their third most important management change. It is also evident from these case studies that precision farming technologies have had little impact on changing the management practices involving pesticide application rates, timing, or products used. Only two growers mentioned pesticide management changes and both ranked these changes near the bottom, signifying their lack of importance.

Successes, Disappointments, and Problems

It is clear that the six growers in this case are at least satisfied with their overall precision farming system they have adopted to date. Three growers stated they were **mostly** satisfied with their system and the other three stated they were satisfied with their system.

The single biggest benefit has been very similar for each of these growers in this case study. All six growers stated in a similar way that they are able to make better, overall management decisions each day with increased confidence.

The most common disappointment has been the lack of technical support to deal with problems with individual precision farming tools and the mapping software. Other disappointments include the lack of being able to justify the adoption because of the high costs, the variability in the grid soil sample results, and the huge learning curve associated with software and the entire precision farming system.

When these growers encounter these problems or challenges with some part or aspect of their precision farming system, they all rely heavily on the manufactures customer support phone number (table 7). Five growers ranked the manufactures customer support phone number high in importance when trying to solve a problem with their precision farming system.

Future Goals and Conclusions

There were several areas where the growers mentioned precision farming could be extremely beneficial to their specific needs in the near future. A few of the growers mentioned the need for more aerial photography providers and experts to get a better understanding of growth and vegetation patterns in their fields during the growing season. The growers also want more raw economic data to estimate profit potential of individual precision farming technologies. One grower mentioned the software and

computer systems used in precision farming need to be more compatible with each other. One farmer felt the need for more local and state extension agent support with precision farming technologies. Another grower mentioned the need for a quicker, easier, and more accurate soil sampling tool linked to precision farming technology to perform on-the-go soil sampling.

The case study results are mixed at best when it comes to whether or not the benefits of precision farming have exceeded the costs. Two growers feel the benefits have clearly exceeded the costs, one is uncertain, and three feel that the benefits have not clearly exceeded the costs of precision farming technologies.

As far as average yields go, four of the growers feel precision farming technologies have produced higher farm average yields, one is uncertain, and one said precision farming technologies have not produced higher farm average yields. These mixed results are limited due the nature of the case study and no statistical analysis can be done. However, the mail survey results will help develop a clearer picture and help answer questions regarding the use, adoption, motivation, costs, and benefits of precision farming technologies in Ohio.

All of the growers were optimistic about precision farming technologies. They were all looking forward to the adoption and use of additional precision farming technologies as they become available in the future. None of these growers plan on abandoning precision farming anytime in the near future. They are all eager to learn more about new technologies that lie ahead. The growers mentioned using more variable

rate technology, aerial photography, and satellite imagery in the future. Others stated they were interested in trying GPS-based variable rate seeding and herbicide application. Soil conductivity and on the go soil sampling or nutrient testing is also a topic of interest among these innovative growers.

CHAPTER 5

A SURVEY OF CENTRAL OHIO PRECISION FARMERS

The purpose of the survey study was to understand PF adoption motivation, how farmers use their PF system, what system components they have adopted, the perceived benefits and costs related to PF adoption, and changes in management practices. A target group of PF adopters was identified with the help of an OSU extension agent in Ohio. Together, a central Ohio cooperative was approached with the survey instrument and the objectives of the study. The cooperative agreed to jointly participate in the study by providing a list of 156 customers that fit the profile of current adopters of PFT. It is important to note that this was not a random sample. Rather, it is the population of precision farming patrons from one central Ohio cooperative. It is believed that these adopters are likely quite similar to other precision farming patrons of other Ohio Cooperatives and, perhaps, to Ohio precision farmers more broadly. Thus, it is expected that the conclusions drawn in this survey study will be applicable to a much larger group of Ohio precision farmers.

The survey was implemented by mail the first week of March 2001 (Appendix C). The sample size was 156 growers who fit our specific criteria. The total return response was 52.56% (82 of 156). Approximately seventy-nine percent (79.27%) of the

respondents were actively farming and completed the questionnaire (65 of 82). About twelve percent (12.20%) of the respondents were no longer farming (10 of 82) and 8.54% percent refused to answer the survey (7 of 82). The rest of this chapter reviews and discusses the results from the survey data gathered. Several summary tables are used to illustrate and clarify the reported results.

Grower Profile

A general profile and characteristic summary of the population of precision farming patrons surveyed is found in table 13. This table also makes comparisons to the Ohio Census of Agriculture statistics. The average size of the surveyed farms is 747 acres. This is substantially greater than the Census average of 206 acres for all farms in Ohio. However, the Census average of farms with more than \$50,000 of annual sales (commercial farms) is 860 acres, which is much more comparable to the survey sample. The sampled farmers derive very little (8.7%) of their gross sales from livestock. The average age for the sample is 49, which is very similar to both Census averages of 53.1 years (all farms) and 50.1 (commercial farms). Forty-four percent (44%) of the sample is full time farmers, which is comparable to the census of 37.1% (all farms) and 57.6% (commercial farms). The sample consists of a large portion of partnerships (24.5%), versus both the all farm Census average of 9.4% and the commercial farm Census average of 15.7%. The sample gender (100% male) is very similar to both the all farm Census average (93.1% male) and the commercial farm Census average (97.5% male) for the farm operator.

Measure	N of Responses	Values from survey sample	Ohio Census of Agriculture (all farms, 1997)	Ohio Census (>\$50,000 annual sales)
Total acres operated (acres)	52	747.42	206	860
Value of sold & stored commodities in 2000 (\$)	38	\$214,435.53		
Gross farm sales from livestock in 2000 (%)	43	8.79%		
Range of off-farm household income (\$)	45			
less than \$25,000		44.44%		
\$25,000 - \$49,999		40.00%		
\$50,000 - \$75,000		11.11%		
more than \$75,000		4.44%		
Age of operator (years)	49	47.04	53.1	50.1
Highest Education level attained	50			
less than high school		0.0%		
some high school		2%		
high school graduate		70%		
some college		10%		
2 year college graduate		8%		
4 year college graduate		6%		
some graduate school		0%		
graduate or professional degree		4%		
Farm operator work off the farm	50			
No		44%	37.1%	57.6%
Yes, seasonally		14%	17.2%	20.1%
Yes, year around		42%	45.7%	22.3%
Type of farming business	49			
sole proprietorship		63.27%	87.1%	76.4%
partnership		24.49%	9.4%	15.7%
corporation		8.16%	2.9%	7.4%
other		4.08%	0.6%	0.5%

Table 13: General Summary of Growers Surveyed

(continued)

Table 13: (Continued)

Measure	N of Responses	Values from survey sample	Ohio Census of Agriculture (all farms, 1997)	Ohio Census (>\$50,000 annual sales)
Sex	50			
male (%)		100%	93.10%	97.50%
female (%)		0.0%	6.90%	2.50%
County of majority of farming operation	51			
Crawford		74.51%		
Richland		11.76%		
Wyandot		1.96%		
Seneca		1.96%		
Huron		5.88%		
Morrow		3.92%		
Number of family employees or farm workers	44			
full-time paid		0.7		
part-time paid		0.48		
full-time unpaid		0.39		
part-time unpaid		0.34		
Number of NON-family employees or farm workers	45			
full-time paid		0.04		
part-time paid		0.69		
full-time unpaid		0.07		
part-time unpaid		0.02		
Grow specialty, value-added or identity preserved crops	48			
acres grown		247.75		
number years growing IP crops		11.33		

Component Adoption

Table 14 summarizes precision farming adoption by individual components. The number of responses for each of the seven components was about 50. The highest adoption percentage, 84.6%, occurred with georeferenced grid soil sampling, followed by 78% adoption of georeferenced variable rate application of lime, 70% VRT phosphorus, and 64% VRT Potassium. Just over 27% have adopted combine yield monitors and only 12% use a satellite GPS receiver with the yield monitor. Extremely low adoption rates occurred with aerial photography, satellite imagery, and georeferenced weed, insect or plant disease scouting. No adoption occurred with variable rate seeding and variable rate applications of pesticides. The majority of PF component adoption occurred during 1997.

Both the combine yield monitor (1,359 ac.) and the GPS receiver (1,709 ac.) are most likely being used on nearly all the crop acres of each farm on which they were adopted. However, georeferenced grid or zone soil sampling and georeferenced VRT of fertilizers and lime are being used on much smaller acreages. This may suggest that the farmers may be experimenting with these components before making large acreage commitments.

Precision Farming Component	N of Responses	Adoption %	Avg. Year Adopted	Avg. Acres Used On (a)	Grid or Management Zone Size (acres)
Georeferenced grid or zone soil sampling					
grids	52	84.62	1997.21	228.3	2.27
management zones	52	25.0	1997.58	181.0	14.81
Combine yield monitor	51	27.45	1997.86	1358.7	na
Satellite GPS receiver with yield monitor	50	12.0	1997	1708.8	na
Georeferenced variable rate application of:					
Lime	50	78.0	1997.51	87.9	na
Nitrogen	50	14.0	1997.71	30.8	na
Phosphorus	50	70.0	1997.47	109.2	na
Potassium	50	64.0	1997.1	110.7	na
Micronutrients	50	2.0	1996	54	na
Manure	50	2.0	1998	10	na
pre-emergent herbicides	49	0.0	na	na	na
post-emergent herbicides	49	0.0	na	na	na
insecticides	49	0.0	na	na	na
fungicides	49	0.0	na	na	na
Georeferenced weed, insect or plant disease scouting	50	2.0	2000	50	na
Georeferenced variable rate seeding	50	0.0	na	na	na
Use of aerial photography, satellite imagery	49	2.04	1996	100	na

Table 14: Farmer Adoption of Precision Farming Technology
(a) - Acreage responses were based on year 2000 only.

The average georeferenced soil grid sample size was 2.27 acres where as the average management zone sample was 14.81 acres. All grid size responses were very concise, with a range of only 1 to 5 acres. However, the management zone sample sizes had a much wider range of 2.27 to 60 acres. There is much less consistency with management zone sizes. All the farmers in this sample who do management zone soil sampling also do grid soil sampling as well. They may be experimenting with both methods to evaluate which works the best for their situation.

Adoption Motivation

Table 15 summarizes farmer evaluation of factors behind adoption of PF components. This table is based on a scoring scale of 0 (not a factor) to 5 (strongly agree). The number of responses to each factor is in column one and the average score for each factor is listed in the last column. The six columns in between break down the individual scale choices by percent. The top three motivational factors (based on average scores) were to increase profits by making better management decisions (4.31), to better understand field variability (3.85), and to stay on top of current technology available to assist in management (3.14). The lowest rated motivation factors were to increase ability to compete for leased land (1.25), future use with identity preserved crops (1.23), and to increase market value of your owned land (1.09).

Motivation Level - Percent (a)								
Motivational Factors	N of Responses	Not a factor 0	Very Low 1	Low 2	Medium 3	High 4	Very High 5	Avg. Score (scale 0-5)
To increase profits by making better management decisions	45	0.0	0.0	4.44	11.11	33.33	51.11	4.31
To better understand field variability (fertility, yield, pH, etc...)	46	6.52	2.17	4.35	4.35	52.17	30.43	3.85
To stay on top of current technology available to assist in management	43	6.98	4.65	13.95	23.26	44.19	6.98	3.14
To keep clearer, more accurate records	44	20.45	4.55	9.09	27.27	22.73	15.91	2.75
To decrease risk/risk management	45	22.22	2.22	8.89	31.11	22.22	13.33	2.69
To conduct on-farm experiments	46	26.09	15.22	10.87	13.04	17.39	17.39	2.33
As a challenge to try something new	43	20.93	11.63	16.28	30.23	18.6	2.33	2.21
To comply with environmental laws or regulations	43	44.19	11.63	6.98	11.63	13.95	11.63	1.74
Price was right/fair for the tools	42	28.57	11.9	23.81	28.57	7.14	0.0	1.74
Its fun and I enjoy learning to use the technology	44	36.36	13.64	9.09	34.09	2.27	4.55	1.66
To project a positive leadership role in community	44	50	9.09	11.36	18.18	11.36	0.0	1.32
To increase ability to compete for leased land	44	56.82	9.09	9.09	6.82	13.64	4.55	1.25
Future use with identity preserved crops	43	53.49	9.3	11.63	13.95	9.3	2.33	1.23
To increase market value of your owned land	45	62.22	6.67	8.89	8.89	8.89	4.44	1.09

Table 15: Primary Motivational Factors for Precision Farming Adoption

(a) - This scale is rated 0 to 5, where 0 means NOT a factor, 1 means very low motivation, and 5 means very high motivation.

Further evaluation of motivational factors reveals that farms greater than 750 acres rate the motivational factor to increase ability to compete of leased land much higher (2.05) than farms less than 750 acres (0.64). A t-test was used to test the equality of means of this motivational factor for the two groups (farm size >750 and farm size < 750) within the sample. The t-test result was significant at the 1% level ($t = -2.81$). This points out that larger size farmers are leasing or renting more land than the smaller acreage farmers, thus this motivational factor is more important to the larger acreage farmers. Also, farms greater than 750 acres rate the motivation factor to keep clearer, more accurate records substantially higher (3.68) than farms less than 750 acres (2.04). The t-test results were significant at the 1% level for this comparison ($t = -3.52$). Since larger farmers have more land and records to manage, they rated this motivational factor higher.

Evaluation of education level revealed that farmers with at least some college education rated the motivational factor to keep clearer, more accurate records higher (3.67) than farmers with an education of a high school diploma and lower (2.39). The t-test was significant at the 3% level, which suggests that farmers with higher education levels place a higher value on the impacts of this technology on record keeping.

Farmers, who leased, rented, or share rented 200 or more acres rated the motivational factor to keep clearer, more accurate records much higher (3.46) than farmers who leased, rented, or share rented less than 200 acres (1.50). The t-test results are significant at the 1% level ($t = -4.31$) meaning there is a difference between the two groups when evaluating the motivational factor to keep clearer, more accurate records.

Also, the farmers, who leased, rented, or share rented 200 or more acres rated the motivational factor to increase ability to compete for leased land higher (1.68) than farmers who leased, rented, or share rented less than 200 acres (0.5). This t-test was also significant at the 1% level ($t = -2.66$).

Relative Benefits and Costs by PF Component

The relative benefits and costs associated with the use of each PF component is evaluated in table 16. Farmers were asked to respond to the statement, “On my farm the benefits of (PF component) clearly exceed its costs”. The scale used was 1 (strongly disagree) to 5 (strongly agree). The summary is questionable for the satellite GPS receiver, georeferenced weed, insect or plant scouting, and aerial photography, satellite imagery due to the very low adoption rates. The combine yield monitor ranked the highest (4.23), signifying that the relative benefits of the combine yield monitor exceed its costs. Georeferenced variable application of fertilizers or lime and georeferenced grid or zone sampling both have average scores greater than 3, suggesting their benefits exceed their costs. One is left with the impression that farmers generally perceive that the benefits exceed the costs for the PF components they adopt and use.

Precision Farming Component (b)	N of Responses	Percent (a)					Avg. Score (scale 1-5)a
		1 (strongly disagree)	2 (disagree)	3 (neutral)	4 (agree)	5 (strongly agree)	
Combine yield monitor	13	0.0	0.0	15.38	46.15	38.46	4.23
Satellite GPS receiver with yield monitor	5	0.0	0.0	0.0	100	0.0	4.0
Georeferenced weed, insect or plant disease scouting	1	0.0	0.0	0.0	100	0.0	4.0
Use of aerial photography, satellite imagery	1	0.0	0.0	0.0	100	0.0	4.0
Georeferenced variable rate application of fertilizers or lime	39	0.0	2.56	20.51	64.10	12.82	3.87
Georeferenced grid or zone soil sampling	41	0.0	4.88	36.59	43.90	14.63	3.68
Georeferenced variable rate application of pesticides	0	na	na	na	na	na	na
Georeferenced variable rate seeding	0	na	na	na	na	na	na

Table 16: Farmer Evaluation of Relative Benefits and Costs for Each PF Component

(a) - This is based on a scale of 1 to 5, with 1 meaning strongly disagree, 2 meaning disagree, 3 meaning neutral, 4 meaning agree, and 5 meaning strongly agree.

(b) - Farmers were asked "On my farm, the **benefits** of a (fill in each precision farming component) clearly **exceed** its **costs**".

Field Variability

Table 17 summarizes several field variability characteristics (soil types, pH, fertility, slope, etc.) ranked on a scale of 1 (very low variability) to 5 (very high variability). All the field characteristics had an average score above 3, except slope (2.85). The field characteristics with the highest variability score are soil pH (3.82), crop yields (3.82), and soil types (3.71). Characteristics with the lowest relative variability are slope (2.85), Nitrogen (3.00) and CEC (3.26)

Further analysis suggests that the total number of PF components a farmer adopts may be associated with the farmer's field variability. As nitrogen, phosphorus, and potassium variability increases, the average number of PF components adopted increases (Average NPK variability score < 3.75, average number of PF components adopted is 1.87; Average NPK variability score \geq 3.75, average number of PF components adopted is 2.60). The same holds for yield, pH, and soil variability. As the variability of these field characteristics increases so does the total number of PF components adopted. The t-test results for the number of PF components adopted reveals that the means are significantly different at the 5% level for the low and high NPK variability groups. The t-test shows the means are significantly different at the 1 % level for the low and high yield variability groups (low = 1.56 components and high = 2.30 components). Also, the means differ with pH variability and are significant at the 10% level (low pH variability = 1.70 components and high pH variability = 2.25 components). However, the t-test results for the number of PF components adopted for the high and low soil variability groups

reveal that the means are not significantly different between these two groups. This result suggests that there is no difference between the number of PF components adopted when soil variability is low or high. However, the overall results above suggest that as field variability increases, farmers are more inclined to adopt more PF components to manage the variability. Alternatively, it may suggest that those farmers who have adopted more PF components are more aware of the variability that exists.

Variability Score - Percent Answering (a)							
Field Characteristics	N of Responses	Very Low 1	Low 2	Medium 3	High 4	Very High 5	Avg. Score (scale 1-5) a
Soil pH	45	0.0	4.44	33.33	37.78	24.44	3.82
Crop yields	45	2.22	4.44	24.44	46.67	22.22	3.82
Soil types	42	0.0	2.38	42.86	35.71	19.05	3.71
Potassium (K)	45	0.0	4.44	35.56	48.89	11.11	3.67
Phosphorus (P)	45	0.0	6.67	40	44.44	8.89	3.56
Drainage	42	2.38	14.29	40.48	33.33	9.52	3.33
Organic matter	41	0.0	17.07	48.78	21.95	12.2	3.29
CEC (cation exchange capacity)	38	0.0	23.68	39.47	23.68	13.16	3.26
Nitrogen (N)	38	10.53	10.53	57.89	10.53	10.53	3.00
Slope	39	15.38	17.95	41.03	17.95	7.69	2.85

Table 17: Field Variability

(a) - this scale is 1-5, where 1 means very low variability and 5 means very high variability.

Costs Associated with Precision Farming Adoption

The various costs associated with the adoption and use of precision farming are identified in table 18. Farmers were asked to evaluate these cost sources using a scale of 0 to 5, where 0 is not a cost, 1 is a low level of cost and 5 is a very high cost. It is clear that these farmers perceive the highest cost associated with the adoption and use of PF to be the service charges for variable application of fertilizers and lime (3.36). The next two highest costs are soil testing fees (2.68) and soil sample collection costs (2.51). Nearly all of the average cost scores (9 of 12) are below 1.50. This suggests that nine of the cost descriptions listed are considered low to very low cost factors associated with the adoption of PF according to the sample surveyed. The lowest cost scores are associated with remote sensing data fees (not a cost for 88% of the farmers)), service fees for variable rate planting (also not a cost for 88% of the farmers) and service fees for VRT application of herbicides, and pesticides (not a cost for 80% of the farmers).

Cost Level - Percent Answering (a)								
Costs	N of Responses	Not a cost 0	Very Low 1	Low 2	Medium 3	High 4	Very High 5	Avg. Score (scale 0-5) a
Service charges for Variable Rate Application of fertilizer/lime	44	0.0	0.0	13.64	45.45	31.82	9.09	3.36
Soil testing fees	44	2.27	15.91	20.45	36.36	22.73	2.27	2.68
Soil sample collection costs	45	8.89	15.56	20	31.11	20	4.44	2.51
Manger time required (including your time)	43	30.23	23.26	27.91	11.63	4.65	2.33	1.44
Consulting fees paid	43	39.53	20.93	16.28	16.28	4.65	2.33	1.33
GPS equipment and differential correction subscription	42	66.67	4.76	0.0	9.52	14.29	4.76	1.14
Input application equipment (spreaders/sprayers/planters)	42	76.19	2.38	0.0	7.14	4.76	9.52	0.90
GIS and mapping software costs	42	71.43	4.76	2.38	11.9	7.14	2.38	0.86
Computer hardware	42	76.19	2.38	4.76	9.52	2.38	4.76	0.74
Service charges for Variable Rate Application of various pesticides	41	80.49	0.0	2.44	9.76	2.44	4.88	0.68
Service charges for Variable Rate Planting	41	87.8	4.88	0.0	2.44	2.44	2.44	0.34
Remote sensing data fees	42	88.1	4.76	0.0	2.38	2.38	2.38	0.33

Table 18: Farmer Evaluation of the Costs Associated with Precision Farming Adoption and Use (a) - this scale is rated 0 to 5, where 0 means NOT a cost, 1 means very low cost, and 5 means very high cost.

Benefits Associated with Precision Farming Adoption

A benefits summary associated with adoption of precision farming is listed in table 19. The same 0 to 5 scale was used to score each possible benefit a farmer may have gained by using PF. The number of responses is listed on the left and the average score of each benefit is listed on the right. The highest rated benefit is precise knowledge of soil pH levels in grids and or management zones (4.07) followed by precise knowledge of soil nutrient levels in grids and or management zones (3.76) and reduction in lime usage (3.25). The lowest ranked benefits include, reduction in insecticide or fungicide usage (0.25), reduction in herbicide usage (0.43), and precise knowledge of weed problem areas (0.89). Most of the farmers surveyed (84.6%) have adopted grid or management zone soil sampling. Many of these farmers rated the precise knowledge of the soil characteristics as the most important benefit gained.

Benefits and Costs of Entire PF System

Survey question B-12 asked farmers the question, “For your farm situation, are the total **benefits** of the precision farming system **greater than** the total **costs** of this system?”

Benefits	N of Responses	Benefit/Value Level (a)						Avg. Score (scale 0-5) a
		Not a benefit 0	Very Low 1	Low 2	Medium 3	High 4	Very High 5	
Precise knowledge of soil pH levels in grids/management zones	43	2.33	0.0	0.0	13.95	53.49	30.23	4.07
Precise knowledge of soil nutrient levels in grids/management zones	45	4.44	0.0	4.44	22.22	44.44	24.44	3.76
Reduction in lime usage	44	9.09	6.82	11.36	15.91	36.36	20.45	3.25
Increased farm average yield	44	9.09	6.82	4.55	31.82	31.82	15.91	3.18
Reduction in fertilizer usage	45	11.11	8.89	6.67	28.89	31.11	13.33	3.00
Decreased variability (risk) in yields	44	25	6.82	13.64	15.91	31.82	6.82	2.43
Better knowledge for future selection of hybrids and varieties	43	32.56	9.3	11.63	11.63	23.26	11.63	2.19
Quantified and precise knowledge of areas of high/low yields	43	46.51	6.98	4.65	11.63	20.93	9.3	1.81
Better environmental records	43	41.86	6.98	11.63	18.6	18.6	2.33	1.72
Improved information for crop rotation management	43	44.19	6.98	25.58	13.95	6.98	2.33	1.40
Identification of drainage problems	45	57.78	8.89	0.0	17.78	11.11	4.44	1.29
Increased ability to compete/negotiate for leased land	43	55.81	6.98	6.98	18.6	9.3	2.33	1.26
Reduction in soil compaction	42	54.76	7.14	11.9	14.29	11.9	0.0	1.21
Better information for crop insurance claims	43	65.12	6.98	6.98	4.65	9.3	6.98	1.07
Knowledge of where equipment failure may have occurred	43	65.12	4.65	11.63	11.63	4.65	2.33	0.93
Precise knowledge of weed problem areas	44	68.18	4.55	4.55	18.18	2.27	2.27	0.89
Reduction in herbicide usage	40	77.5	12.5	0.0	10	0.0	0.0	0.43
Reduction in insecticide or fungicide usage	44	86.36	6.82	2.27	4.55	0.0	0.0	0.25

Table 19: Farmer Evaluation of the Benefits Gained from Precision Farming Adoption and Use

(a) – this scale is rated 0 to 5, where 0 means NOT a value/benefit, 1 means very low value/benefit, and 5 means very high value/benefit.

To help farmers think through this statement, they were directed to consider the list of costs summarized in table 18 and the list of benefits summarized in table 19. Table 20 summarizes the responses for the full sample and for farmers categorized by, education level, farm size, age, and number of PF components adopted. The scale of 1 to 5 was used to calculate average response, where 1 is “No, Costs are significantly greater than Benefits” and 5 is “Yes, Benefits are significantly greater than Costs”. The average response for the sample is 3.76. Ninety five percent of the sample (40 of 42) gave a score of 3 or above. Thus, there seems to be substantial evidence that these adopters consider PF to be a worthwhile investment.

A simple comparison of the means suggests that farmers with higher formal education levels derive greater net benefits from their precision farming system. Farmers with at least some post-high school education have evaluations 0.22 points higher. However, a t-test reveals that this difference is not statistically different from zero. Farm size had no impact on the average benefit cost score (3.76 vs. 3.76). However, the t-test on farm size and benefit cost score was not significant ($t = -0.02$). Younger farmers ranked the average benefits slightly higher than the older farmers (3.79 vs. 3.69). However, the t-test ($t=0.43$) suggests the difference between age groups is not significant, meaning there is statically no difference between the average benefit cost scores of the two age groups. Farmers who have adopted and use three or more PF components ranked the average benefits slightly higher than farmers who adopted and use one or two PF components (3.90 vs. 3.72). However, this comparison was also not significant ($t=-0.72$). A final point shows that no farmers answered, “No, Costs are significantly greater than Benefits” to this question.

Characteristics	N of Responses	Response (a)					Avg. Score (scale 1-5)
		1	2	3	4	5	
All Producers in Survey	42	0.0	4.76	23.81	61.9	9.52	3.76
Education level is high school graduate or lower	30	0.0	6.67	23.33	63.33	6.67	3.70
Education level above high school graduate	12	0.0	0.0	25.0	58.33	16.67	3.92
Farm 750 acres or less	25	0.0	4	20.0	72.0	4.0	3.76
Farm more than 750 acres	17	0.0	5.88	29.41	47.06	17.65	3.76
Farmers 48 years old or younger	29	0.0	3.45	27.59	55.17	13.79	3.79
Farmers greater than 48 years old	13	0.0	7.69	15.38	76.92	0.0	3.69
Adopted and use one or two PF components	32	0.0	3.13	28.13	62.5	6.25	3.72
Adopted and use three or more PF components	10	0.0	10.0	10.0	60.0	20.0	3.90

Table 20: Overall Benefits and Costs of Entire Precision Farming System

(a) - Farmers were asked, "For your farm situation, are the total **benefits** of the precision farming system **greater than** the total **costs** of this system?"

- (1) - No, Costs are significantly greater than Benefits
- (2) - No, Costs are slightly greater than Benefits
- (3) - Benefits and Costs are about equal
- (4) - Yes, Benefits are slightly greater than Costs
- (5) - Yes, Benefits are significantly greater than Costs

Changes in Management Practices

Management changes that are a direct result of PF adoption are evaluated in Table 21. The same scale of 1 (strongly disagree) to 5 (strongly agree) is used. Eleven possible management changes were listed for the farmers to respond to. Clearly, the management practice changed most often as a result of PF adoption is the amount of fertilizers or lime applied (4.24). The timing of fertilizer applications also was important, ranking 5th with a mean score of 3.04. The average score for the amount of fertilizers or lime applied is substantially higher than the second most often changed management practice, hybrid or seed varieties planted (3.25). Five of the eleven management changes have an average score above 3, suggesting some level of change. Six of the eleven management changes have an average score below 3, suggesting no substantial change. The three lowest average scores were all associated with pesticides. This implies that PF adoption has not made an impact in regards to changing existing **pesticide** management practices. Clearly, this is consistent with the fact that none of the respondents have adopted variable rate application of pesticides (herbicides, insecticides, and fungicides).

Score - Percent Answering (a)							
My Precision Farming System has changed.....	N of Responses	Strongly disagree 1	Disagree 2	Neutral 3	Agree 4	Strongly agree 5	Avg. Score (scale 1-5) a
the <u>amount</u> of fertilizers or lime that I apply	45	0.0	0.0	2.22	71.11	26.67	4.24
the hybrid or seed varieties I plant	44	9.09	2.27	54.55	22.73	11.36	3.25
how I make tiling decisions (new tile, tile repairs)	43	16.28	0.0	48.84	25.58	9.3	3.12
the planting <u>populations</u> I use	44	13.64	2.27	52.27	29.55	2.27	3.05
the <u>timing</u> of my fertilizer applications	45	6.67	11.11	55.56	24.44	2.22	3.04
the tillage practices I use	44	15.91	4.55	52.27	27.27	0.0	2.91
the crop rotation or sequence I follow	43	18.6	2.33	62.79	13.95	2.33	2.79
the <u>timing</u> of my plantings	44	15.91	4.55	75.0	4.55	0.0	2.68
the <u>rate</u> of my pesticide applications	44	18.18	6.82	68.18	6.82	0.0	2.64
the <u>timing</u> of my pesticide applications	44	18.18	6.82	72.73	2.27	0.0	2.59
the <u>pesticide products</u> I use	44	20.45	9.09	68.18	2.27	0.0	2.52

Table 21: How the Precision Farming System Changes Management Practices/Decisions
(a) - this is based on a scale of 1 to 5, with 1 meaning strongly disagree, 2 meaning disagree, 3 meaning neutral, 4 meaning agree, and 5 meaning strongly agree

Satisfaction, Profitability, and Future of PF

Table 22 describes the satisfaction, profitability, and future of PF based on responses from five different questions from the survey. The same scale of 1 (strongly disagree) to 5 (strongly agree) is used to evaluate each question. The average score for the satisfaction level of the precision farming service provided by the local co-op or retailer was 4.02, which was the highest average score. Average satisfaction with the entire precision farming system adopted was 3.75. The average score for belief that precision farming technologies have increased farm profitability was 3.76. Plans to continue to adopt precision farming tools in the future scored 3.98, implying continued adoption. The last question asked about the belief that crop yields have increased since adoption of PF, which scored 3.68. The responses to these five questions all average above 3.50, which suggests an overall positive outlook for PF satisfaction, profitability, and for the future of PF. Also, no farmer answered a 1 (strongly disagree) to any of these five questions.

Score - Percent Answering (a)							
Statements	N of Responses	Strongly disagree 1	Disagree 2	Neutral 3	Agree 4	Strongly agree 5	Avg. Score (scale 1-5) a
I am very satisfied with the precision farming services provided by my Co-op/ Ag.Retailor.	44	0.0	4.55	13.64	56.82	25.0	4.02
I am very satisfied with my precision farming system.	44	0.0	0.0	36.36	52.27	11.36	3.75
I believe that precision farming technologies have increased the profitability of my farm.	45	0.0	0.0	31.11	62.22	6.67	3.76
I plan to continue adoption of precision farming tools in the future.	45	0.0	4.44	6.67	75.56	13.33	3.98
I believe that my crop yields have increased since adoption of precision farming systems.	45	0.0	2.22	33.33	57.78	6.67	3.68

Table 22: Satisfaction, Profitability, and Future of Precision Farming
(a) - this is based on a scale of 1 to 5, with 1 meaning strongly disagree, 2 meaning disagree, 3 meaning neutral, 4 meaning agree, and 5 meaning strongly agree

Multivariate Regression Analysis

The evaluation and analysis of the survey data in the above paragraphs points out several similarities and differences surrounding PF motivation, adoption, benefits, costs, and management changes among farmers. It is evident that differences exist among the farmers with regards to how they evaluate their PF system. Therefore, a multivariate statistical analysis is used to further evaluate the survey data gathered. Four multivariate models were used to statically examine four dependent variables. The four dependent variables include an overall benefit-cost ratio for the entire PF system and three measures of change in management decisions resulting from the use of PF: fertility, pesticide, and planting management change. The models all use farmer and farm business characteristics as well as characteristics of the farms precision farming system (independent variables) to attempt to explain each dependent variable. Below, each model will be discussed and the statistical estimates evaluated.

Benefits and Costs Model

A multivariate regression model was formulated to evaluate farmers' perceptions of the relative benefits and costs of their overall PF system. The dependent variable is based on survey question B-12: "For your farm situation, are the **total benefits** of the precision farming system **greater than** the **total costs** of the system?" The responses were recoded as follows: 1 = No, costs are significantly greater than benefits, 2 = No,

costs are slightly greater than benefits, 3 = Benefits and costs are about equal, 4 = Yes, benefits are slightly greater than costs, 5 = Yes, benefits are significantly greater than costs. The independent variables consisted of various characteristics of the farmer, the farm business, and characteristics of the farm's precision farming system. The equation assembled was:

$$\text{BC Ratio} = b_0 + b_1 \text{PFTexp} + b_2 \text{totac} + b_3 \text{educ} + b_4 \text{yieldvar} + b_5 \text{pHvar} + b_6 \text{YM} + b_7 \text{GPS} + b_8 \text{vrtLime} + b_9 \text{interact} + e_i$$

where BCRatio is the score of the overall benefits and costs associated with adoption and use of PF components; *PFTexp* is number of years experience the farmer has had since their earliest adopted PF component; *totac* is the total number of acres actively farmed; *educ* is 1 if the farmer has some college education or higher and is otherwise 0; *yieldvar* is a normalized measurement of yield variability (based on survey question B-9); *pHvar* is a normalized measurement of soil pH variability (based on survey question B-9); *YM* is 1 if the farmer has adopted a combine yield monitor and is 0 otherwise; *GPS* is 1 if the farmer has adopted a GPS receiver and is 0 otherwise; *vrtLime* is 1 if variable application of lime was adopted and 0 otherwise; and *interact* is the product of *pHvar* and *vrtLime*, and thus allows for a shifting in the slope of *pHvar* when *vrtLime* = 1.

The purpose of the BC Ratio model is to determine what characteristics and attributes explain how farmers evaluate the overall benefits and costs associated with PF adoption and use. Several independent variables were chosen to explain the BC Ratio model.

Farm size (*totac*) is included in the model because many previous studies have found size of business to be an important determinant of technology adoption. Larger

acreage farmers tend to be leaders in innovation. For investments with substantial fixed costs, larger farms allow spreading of these costs over more acres, thus lowering average fixed costs to levels less achievable than with smaller acreage farms. In the case of precision farming, the fixed costs of capital equipment can be large and the fixed costs of learning to use the system and to develop the knowledge of how to make appropriate decisions (human capital) are substantial.

Education (*educ*) and years of experience with the PF system (*PFTexp*) are also included as measures of human capital on the farm. As farmers become more experienced with their PF components, they may discover additional benefits or costs associated with their use and they may derive increased net benefits from the PF system. Similarly, education level is important because it provides a better basis for farmers to understand their business and make informed management decisions.

A hypothesis of this study is that the profitability of the PF system is expected to increase as the relative variability within fields increases, thereby creating value to site-specific management. Yield (*yieldvar*) and soil pH variability (*pHvar*) are included in the model to reflect overall variation in crop yields and in soil pH. These measures, based on survey question B-9, have been normalized so that the mean score is zero and increased scores indicate greater variability. For example, soil pH variability (*pHvar*) was normalized by subtracting the sample mean score for soil pH variability from the individual farmers score for their soil pH variability ($pHvar = \text{farmer's soil pH variability score} - \text{sample's mean score for soil pH variability}$). Thus, the mean for *pHvar* is zero and its variability is unchanged from the original measure. The same process was used to calculate the normalized score for yield variability (*yieldvar*).

Adoption of specific PF components is hypothesized to influence the effectiveness of the PF system. Yield monitor and GPS receiver adoption tend to be the first two PF components adopted. They are data collection technologies. The yield monitor allows measurement of crop yields on the go. Combined with the GPS receiver, this data can be georeferenced and later analyzed through yield maps or by statistical means. Also, variably applied lime adoption is included in the model. Anecdotal evidence from farmers and agribusiness suggest that variably applied lime has a high profit potential. *Interact* is a slope-shifting binary variable that reflects the joint effect of pH variability and VRT lime application in the determination of the BC Ratio.

Table 23 reports the estimated coefficients, sample size, R-squared, Adjusted R-squared, and the model F value. The F value of 2.88 suggests that the model is significant at the 2% level. The adjusted R-square indicates that approximately 33 percent of the variation in the dependent variable is explained by the model.

PF experience is positive, which suggests that a one year increase in PF experience is associated with a 0.06 increase in BC Ratio, with all other variables held constant. While, PF experience is not significant at the 10% probability level, the t-value is relatively large indicating significance at the 18% probability level. Education is positive, but significant only at the 16% level. The positive coefficient suggests that an increase in formal education, with all else equal, farmers' evaluation of net benefits of their PF systems also increase. Although not significant at the critical level, there is some evidence to support the hypothesis that the amount of human capital is an important determinant of the usefulness of the system. Total acres and yield variability are negative, but not significant.

Variable	Parameter		
	Estimate	t Value	Pr > t
Intercept	3.61038	6.08	<.0001
PF Experience	0.06159	1.37	0.1816
Total Acres	-0.00025	-1.24	0.2271
Education	0.35363	1.44	0.1604
Yield Variability	-0.09531	-0.79	0.4386
pH Variability	-1.14005	-1.57	0.1284
Yield Monitor	-0.74492	-1.72	0.0972
Yield Monitor & GPS	1.13814	2.98	0.0062
VRT Lime	0.01058	0.02	0.986
Interaction	1.30925	1.82	0.0796
	N	35	
	R-Squared	0.50	
	Adjusted R-Squared	0.33	
	Model F Value	2.88	

Table 23: Regression of Farmer Characteristics and PF Components on BC Ratio

Presence of a yield monitor is negative and significant at the 10% level. This means that when **only** a yield monitor is adopted in the **absence** of a GPS receiver (GPS=0), all other things constant, there is a 0.74 decrease in the BC Ratio. At face value, this is an unusual result. However, when the yield monitor **and** GPS receiver are used **together** (YM and GPS both=1), the parameter estimate becomes significantly **positive** at the 1% level. Thus, while the yield monitor alone is associated with a 0.74 decrease in BC Ratio, the net effect of both the yield monitor and the GPS receiver is a 0.4 (-0.74+1.14) increase in BC Ratio. Figure 5 illustrates the line shifting.

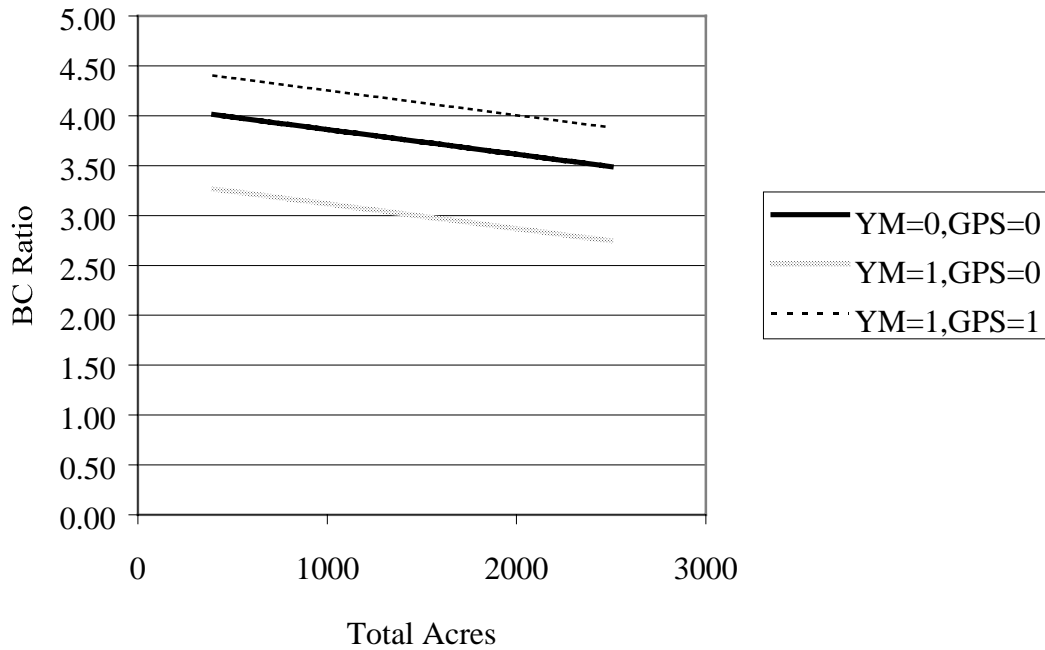


Figure 5: Effect of Yield Monitor Only and Yield Monitor and GPS Receiver Together

The parameter estimate on pH variability is negative and is approaching the 10% significance level. This suggests that a one unit increase in pH variability score results in a 1.14 decrease in BC Ratio, all other variables held constant. This suggests that as pH variability increases there would be a decrease in the BC Ratio. VRT lime is positive, but not significant. Because *vrtLime* is an intercept-shifting binary variable, the lack of significance implies that the intercept for the function is not changed with the adoption of VRT lime applications. However, the interaction term is positive and significant at the 10% level. *Interact* captures the joint effect of pH variability and VRT Lime on overall BC Ratio score. In the absence of variable rate lime application (VRT Lime=0), pH variability (uncontrolled) decreases the producers' evaluation of their system. However,

with the ability to manage this variability using variable rate application (VRT Lime=1), the producer derives increased value from the overall system as pH variability increases. Figure 6 graphically explains how pH variability and VRT Lime interact to change the BC Ratio as all other variables are held constant.

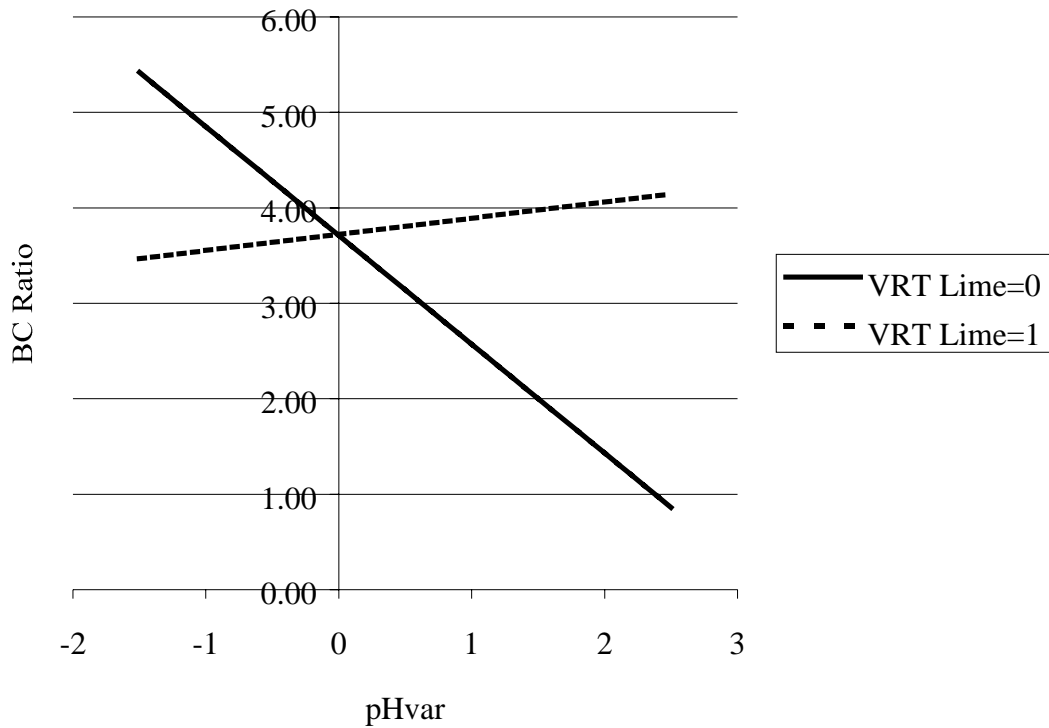


Figure 6: Interaction Effect of VRT Lime and pHvar

Fertility Management Change Model

A multivariate regression model was formulated to evaluate fertility management changes that may have occurred as a direct result of PF adoption. The purpose of the Fertility Management Change model is to determine what characteristics and attributes

explain the level of fertility management changes that are made relative to all management changes that occurred as a direct result of PF adoption. The dependent variable is based on two parts of survey question B-13, specifically, “My PF system has changed...the amount of fertilizers or lime that I apply” and “... the timing of my fertilizer applications”. Each question was scaled from 1 (strongly disagree) to 5 (strongly agree). The respondent's mean of these two questions was determined and was divided by the mean of that individual's responses to all eleven questions that comprise question B-13. This resulted in a fertility management changes score that is measured relative to all management changes made by that farmer. For example, if a farmer responded to the two fertility questions with 4's (agree) and gave strongly disagree responses (1's) to the other nine questions, his fertility management score would be 2.59. That is, the mean response to the fertility questions is 2.59 times larger than the mean for the eleven questions. A second individual might also give 4's to the fertility decisions, but might evaluate all other decisions with 3's. Thus, the fertility decision score for this latter respondent would be 1.26. Clearly, the first respondent has given stronger signals that the fertility decision has changed than has the second individual. The mean for the fertility management change dependent variable was 1.278. It ranged in value from 0.939 to 2.588.

The independent variables included in the model were various characteristics of the farmer, the farm business, and characteristics of the farm's PF system. The constructed equation was:

$$\text{Fertility Manage Changes} = b_0 + b_1 \text{PFTexp} + b_2 \text{totac} + b_3 \text{educ} + b_4 \text{soilvar} + b_5 \text{PKvar} + b_6 \text{pHvar} + b_7 \text{YM} + b_8 \text{GPS} + b_9 \text{vrtLime} + b_{10} \text{vrtPK} + e_i,$$

where Fertility Manage Changes are the fertility changes made relative to all other management changes that occurred as a result of PF adoption;

PFTexp is the number of years experience the farmer has had since their earliest adopted PF component;

totac is the total number of acres actively farmed;

educ is 1 if the farmer has some college education or higher and is otherwise 0;

soilvar is a normalized measurement of soil variability (based on survey question B-9);

PKvar is a normalized measurement of potassium and phosphorus variability (based on survey question B-9);

pHvar is a normalized measurement of soil pH variability (based on survey question B-9);

YM is 1 if the farmer has adopted a combine yield monitor and is 0 otherwise;

GPS is 1 if the farmer has adopted a yield monitor and GPS receiver and is 0 otherwise;

vrtLime is 1 if variable application of lime was adopted and 0 otherwise;

vrtPK is 1 if variable application of potassium or phosphorus was adopted and 0 otherwise.

Farm size (*totac*) is included in the model because many previous studies have found size of business to be an important determinant of management styles and techniques. Also, for investments with substantial fixed costs, larger farms allow spreading of these costs over more acres, thus lowering average fixed costs to levels less achievable than with smaller acreage farms. Also, farm size (*totac*) may influence how fertility management changes are made due to differences in fixed costs, equipment costs, and human capital.

Education (*educ*) and years of experience with the PF system (*PFTexp*) are also included in the model. As farmers become more experienced with their PF components, they may discover additional information that could lead to fertility management changes or adjustments. Similarly, education level is important because it provides a better basis for farmers to understand their business and make informed fertility management decisions or changes.

Soil (*soilvar*), potassium and phosphorus (*PKvar*), and soil pH (*pHvar*) variability are included in the model to reflect overall variation in soil type, potassium, phosphorus, and soil pH. These measures, based on survey question B-9, have been normalized so that the mean score is zero and increased scores indicate greater variability. Additional knowledge of this variability obtained through PF adoption could impact the fertility management decisions a farmer makes.

Adoption of specific PF components can also lead to an increase of knowledge. Yield monitors and GPS receivers can provide a wealth of information and knowledge from which many fertility management changes could be based. These components can provide insights and information that were previously unknown and thus never considered when making previous management decisions. Variable application of lime, potassium, and phosphorus are also included in the model for the same reasons mentioned above.

Table 24 reports the estimated coefficients, sample size, R-squared, Adjusted R-squared, and the model F value. The F value of 0.91 suggests that the model is not statistically significant at the usual critical levels. The adjusted R-squared (-0.02) indicates that the model explains virtually none of the variation in the dependent variable.

Variable	Parameter		
	Estimate	t Value	Pr > t
Intercept	1.10062	3.69	0.001
PF Experience	0.0052	0.14	0.886
Total Acres	0.00005638	0.40	0.6904
Education	0.11643	0.67	0.5078
Soil Variability	0.27644	1.84	0.0765
P & K Variability	-0.27701	-1.81	0.0804
pH Variability	-0.05043	-0.44	0.6651
Yield Monitor	-0.24096	-0.81	0.4251
Yield Monitor & GPS	0.06817	0.24	0.8092
VRT Lime	0.13579	0.50	0.6203
VRT P and/or K	0.04259	0.20	0.8398
	N	38	
	R-Squared	0.25	
	Adjusted R-Squared	-0.02	
	Model F Value	0.91	

Table 24: Regression of Farmer Characteristics and PF Components on Fertility Management Changes.

All of the independent variables are insignificant except for soil variability (*soilvar*) and PK variability (*PKvar*). The parameter estimate on soil variability is positive and significant at the 10% level. It suggests that as soil variability score increases one unit, the likelihood of fertility management changes will increase 0.28 relative to the average of all other management changes all else constant. PK variability is negative and significant at the 10% level. It suggests that as PK variability score increases one unit, the likelihood of fertility management changes would **decrease** 0.28

relative to the average of all other management changes all else constant. However, the model as a whole is statistically very weak and the independent variables do not explain the variation in the dependent variable. The reason for the lack of statistical strength could be a result of the use of incorrect independent variables, a poorly defined dependent variable, or a combination of both. The evidence is clear that the model has very little statistical significance.

Pesticide Management Change Model

Another multivariate regression model was formulated to evaluate pesticide management changes that may have occurred as a direct result of PF adoption. The dependent variable is defined in the same manner as for the fertility decision model, but is based on three different parts of survey question B-13, specifically, “My PF system has changed...the rate of my pesticide application,” “the timing of pesticide applications,” and “the pesticide products I use.” The mean of these three specific questions was determined and then the mean score was divided by the entire mean of all answers to B-13. The mean for the pesticide decision dependent variable was 0.852. It ranged in value from 0.423 to 1.283. Comparison of the mean pest decision measure to that of fertility decisions in the previous model suggests that these farmers have evaluated changes in the pest area to be less frequent than changes in the fertility decision area.

The estimated equation was:

Pesticide Manage Changes = $b_0 + b_1 PFTexp + b_2 totac + b_3 educ + b_4 soilvar + b_5 pHvar + b_6 YM + b_7 GPS + e_i$, where Pesticide Manage Changes are the pesticide changes made

relative to all other management changes that occurred as a result of PF adoption. All independent variables are as defined in the fertility management model.

Soil (*soilvar*) and soil pH (*pHvar*) variability are included in the model to reflect overall variation in soil type and soil pH. Again, these measures have been normalized so that the mean score is zero and increased scores indicate greater variability. Variation of soil types and soil pH levels may interact with herbicide types and may influence optimal application rates. Hence knowledge of these values may impact the pesticide management decisions a farmer makes.

Both yield monitors and GPS receivers were included in the model. These components can provide a wealth of information and knowledge from which many pesticide management changes could be based. Yield maps may allow the farmer to relate previous yields to know weed problem areas, and emphasize the need for changed weed control programs. They may also allow on-farm experimentation with herbicides, thereby supporting improved decision making and management.

Table 25 reports the estimated coefficients, sample size, R-squared, Adjusted R-squared, and the model F value. The F value of 2.74 suggests that the model is significant at the 3% level. The adjusted R-squared (0.23) indicates that approximately 23 percent of the variation in the dependent variable is explained by the model.

PF experience is negative and significant at the 10% level. Total acres are also negative, but significant at the 11% level. This suggests that one unit increases in these variables results in decreases in the likelihood of changed pesticide management

Variable	Parameter		
	Estimate	t Value	Pr > t
Intercept	1.02402	15.38	<.0001
PF Experience	-0.03125	-1.78	0.0851
Total Acres	-0.0000812	-1.66	0.107
Education	0.01343	0.23	0.8229
Soil Variability	0.0514	1.00	0.3228
pH Variability	-0.0443	-1.09	0.2826
Yield Monitor	0.10226	1.16	0.2548
Yield Monitor & GPS	-0.17869	-1.84	0.0741
	N	40	
	R-Squared	0.37	
	Adjusted R-Squared	0.23	
	Model F Value	2.74	

Table 25: Regression of Farmer Characteristics and PF Components on Pesticide Management Changes.

decisions relative to changes in other management decisions. This result suggests that as precision farming experience or total acres increase, all else unchanged, pesticide decision changes are less likely to occur than are changes in other management decisions.

Adoption of a yield monitor plus a GPS receiver is negative and significant at the 10% level. This means that adoption of these two components results in a decrease in the likelihood of changing the pesticide management decisions relative to other management changes. This result may be due to the reasoning that very few farmers are focused on PF technology that is specific to pesticide management. They are much more focused on lime and fertility PF, thus this may explain why pesticide management changes are less

important relative to all other management changes. However, it also may suggest that farmers, through improved crop performance information derived from the yield maps allowed with both a yield monitor and a GPS receiver, may have discovered that pesticide decisions are not as important in a site-specific management system as are fertility and planting decisions. Lastly, education, soil variability, pH variability, and yield monitor are all insignificant in this model.

Planting Management Change Model

Finally, a multivariate regression model was formulated to evaluate planting management changes that may have occurred as a direct result of PF adoption. Again, the dependent variable was formulated as in the fertility and pesticide decision models but was based on three different parts of survey question B-13, specifically, “My PF system has changed...the planting populations I use”, “the hybrid or seed varieties I plant” and, “the tillage practices I use.” The mean for the planting decision dependent variable was 1.016. It ranged in value from 0.550 to 1.692. Thus, planting decision changes were valued as approximately average in value, lower in importance than the fertility decision, but more likely to be changed than the pesticide decisions.

The estimated equation was:

Planting Manage Changes = $b_0 + b_1 PFTexp + b_2 totac + b_3 educ + b_4 soilvar + b_5 yieldvar + b_6 YM + b_7 GPS + e_i$, where Planting Manage Changes are the planting changes made relative to all other management changes that occurred as a result of PF adoption.

The purpose of the Planting Management Change model is to determine what characteristics and attributes explain the likelihood of planting management changes that are made relative to **all** management changes that occurred as a direct result of PF adoption. The seven independent variables included in this model were included for the same reasons as in the previous models.

The results of the Planting Management Change model are reported in table 26. The F value of 1.30 suggests that the model is significant only at the 30% level. The adjusted R-squared (0.05) indicates that approximately 5 percent of the variation in the dependent variable is explained by the model.

Variable	Parameter		
	Estimate	t Value	Pr > t
Intercept	0.92192	12.03	<.0001
PF Experience	0.01679	0.84	0.4092
Total Acres	0.00002222	0.42	0.6774
Education	-0.0286	-0.43	0.6671
Soil Variability	-0.01368	-0.32	0.7487
Yield Variability	0.02401	0.71	0.4812
Yield Monitor	0.03325	0.34	0.7326
Yield Monitor & GPS	0.1115	1.02	0.3172
	N	39	
	R-Squared	0.22	
	Adjusted R-Squared	0.05	
	Model F Value	1.30	

Table 26: Regression of Farmer Characteristics and PF Components on Planting Management Changes.

Every parameter estimate is highly insignificant. Therefore, it is not possible to draw any sound conclusions from the existing model. The reason for the lack of statistical significance could be a result of the use of incorrect independent variables, a poorly defined dependent variable, or a combination of both. Unfortunately, the evidence is clear that the model has very little statistical significance.

CHAPTER 6

FINAL RESULTS AND CONCLUSIONS

Included in this final chapter are the major results and conclusions from the case studies and the survey questionnaire. Quantitative and qualitative data gathered from the case studies and from the survey have been analyzed in the previous chapters. Here in chapter 6, the objectives and the hypotheses are reviewed and conclusions are drawn based on all data and observations gathered.

This in-depth study of precision farming was important for several reasons. Precision farming technology is designed to provide extensive information and data to assist farmers when making site-specific management decisions. By making more informed and better management decisions, farmers can become more efficient, lower production costs, and, in turn, become more profitable. However, little is currently known about how farmers use PF technologies to make management decisions or identify production problems, or about the relative magnitude of benefits and costs of PF technologies on individual farms. Therefore, research of precision farming technology is needed to assist the Ohio agricultural community in finding answers to questions surrounding the adoption, use, and the potential management benefits of precision farming technology.

As stated by Yin (1994, p.1) the case study approach is useful, “when **how** or **why** questions are being posed, when the investigator has little control over events, and when the focus is on a contemporary phenomenon within some real-life context”. The goal of the research from the six case studies reported in this thesis is to explain, understand, and answer the “how” and “why” questions motivating adoption and uses of precision farming, and the management practices that have been changed among Ohio farmers as a result of PF adoption. Therefore, an embedded, multiple-case study approach was used to collect information about precision farming from six different farms, which fit specific criteria. The criteria were the six farms must have adopted at least three precision farming technologies and have used PF for at least two years.

Significant qualitative and some quantitative data were collected from these six farm cases. All data collected followed a strict data collection protocol, which included a single researcher administering a flexible, open-ended questionnaire designed to limit bias. The evidence and data were collected through the case study interviews and were documented through written summaries and audio recordings.

By following the above case study method, detailed information was gathered and case-by-case reports were written along with a detailed cross-case report. The major results and conclusions of the six case studies are reported later in this chapter.

Information obtained from the six case studies was used to assist in the development of a survey questionnaire administered by mail to a larger group of PF adopters. A target group of PF adopters was identified with the help of an OSU extension agent. Together, a central Ohio cooperative was approached with the survey instrument and the objectives of the study. The cooperative agreed to jointly participate

in the study by providing a list of 156 customers that fit the specific criteria of current adopters of PF. It is important to note that this was not a random sample. Rather, it is the population of precision farming patrons from one central Ohio cooperative. It was believed that these adopters were likely quite similar to other precision farmers in Ohio, thus it was expected that the conclusions drawn in this study will be applicable to a much larger group of Ohio precision farmers.

The numerical rankings, data, and information collected from the returned surveys were analyzed through statistical measures using the Statistical Analysis System (SAS) software. Four regression models were constructed from the survey data to statistically test hypotheses involving motivational factors, cost factors, benefit factors, and various management practice changes. Parameter coefficients, F values, and t values, were estimated and conclusions drawn. The major results and conclusions are summarized next in this chapter.

Major Conclusions from the Case Studies

The major conclusions and results of the six case studies are discussed in the following paragraphs. Farm business characteristics, precision farming component adoption, motivation and benefits of PF adoption, and satisfaction and future plans with PF are all summarized.

All six farmers interviewed had much larger farm sizes than the average farm size in Ohio of 206 acres. This may be a result of larger economies of scale or the fact that larger farmers tend to adopt new technology. Also, the specific criteria set forth for

the case studies called for progressive and early adopters of PF. Therefore, caution should be taken when considering the conclusions drawn from the six case studies due to how the six cases were selected. All six farmers had little to no education beyond a high school diploma. A two-year associates degree was the highest level of education achieved among the six farmers. This advocates that even though formal education may be helpful, these farmers were able to effectively implement this technology without college-level education. Also, all six were grain farmers and only one farmer raised livestock. This may be due to the fact that PF to date deals primarily with crop management information and little with livestock management. Finally, four of the six farmers had family members involved in the operation as part owners or partners of the business. This implies that family members continue to play a major role in farming operations as PF is adopted.

The most commonly adopted PF components were yield monitors, GPS receivers, GIS mapping software, and GIS grid or zone management soil sampling. All six of the farmers in the case studies were using these four PF components. Five of the six farmers were using a 2 to 3 acre grid soil sampling method. Only one farmer mentioned using a management zone method for collecting soil samples. Four of the six farmers were using VRT application of lime. One of the remaining two growers planned to adopt this component within the next 3 months. The other planned to adopt in the next one to three years. Despite the adoption of VRT lime application, there was a definite lack of variable rate seeding and variable rate pesticide application adoption. According to these six growers, this was primarily due to the lack of economic evidence that these other two (seed and pesticide) variable rate technologies showed profitability. For these farmers,

the yield monitor seemed to be the starting point for adoption. Four of the six reported adopting this component first; the other two adopted grid or management zone soil sampling as the first component. Also important, is the addition of a GPS receiver to the yield monitor: Five of the six added a GPS receiver within one year of adopting the yield monitor. Another key discovery was that variable rate application of fertilizers and various pesticides was not uniformly adopted. Only four of the six farmers adopted VRT of fertilizers or lime, and only two of these use it on 100 percent of their acres. One of the four does VRT lime only and one was experimenting with about 15% of his land in VRT fertilizer application. Only one farmer was using VRT application of herbicides. The other five made it clear that they found no persuasive evidence to suggest that VRT application of herbicides is feasible or economically practical at this point.

The most important PF component for the case farms was the yield monitor (3 of 6 farmers indicated this), followed by georeferenced soil testing (2 of 6) and the GPS receiver (1 of 6). If one considers the top three most important components identified by each of the case farmers, they are (in decreasing order) yield monitor, GPS receiver, GIS mapping, georeferenced soil sampling, and VRT fertilizer/lime application.

The results of motivation, goals, and benefits of PF adoption consisted of three major findings. The most common motivational factor behind adoption of PF is to increase profits. Five of the six farmers mentioned this as their number one motivational factor behind PF adoption and the sixth grower mentioned it as their number two motivational factor. When the case farmers top three individual motivating factors are all considered, the top motives, in decreasing order of importance, are to increase profits, to allow on-farm experimentation, to better understand field variability, to decrease risk, and

to improve environmental compliance. All six growers mentioned that the most important goal with their precision farming system was to make better daily management decisions based on the information and data they gathered from their PF system. According to these six farmers, the most common benefit gained from the adoption of a PF system was the precise knowledge of crop yields and variability.

Major conclusions involving satisfaction and future plans with PF are summarized next. All six are at least satisfied with their overall PF system. They all gave a rating of satisfied, mostly satisfied, or very satisfied when asked about their entire PF system. When asked, “Do the benefits of your precision farming system exceed its costs?”, two of the six producers said yes, three said no, and one was uncertain. Still, the six growers all gave an extremely optimistic outlook on the future of PF. All six plan to continue to adopt additional PF components in the future. Finally, a common theme among these six growers was the need for future PF components to have the ability to perform on the go soil nutrient or crop evaluations.

Major Conclusions from the Survey

The survey was administered in early March 2001 to a sample of 156 growers who are precision farming customers of a central Ohio cooperative. The total return response was 52.56% (82 of 156). Seventy-nine percent of the respondents were actively farming and completed the questionnaire (65 of 82). Twelve percent of the respondents were no longer farming (10 of 82) and 8.54% refused to answer the survey (7 of 82). The following paragraphs discuss the conclusions from this survey.

The average farm size surveyed was 747 acres, much larger than the average Ohio farm size of 206 acres. Ninety-eight percent of the farmers surveyed had at least a high school diploma. Sole proprietorships comprise 63% of the farmers surveyed. Also, 56% worked off the farm yearly or seasonally.

The highest-rated motivational factor associated with the adoption and use of PF was to increase profits by making better management decisions (4.31 on a scale of 5.0). The two most frequently adopted components are grid or zone management soil sampling (85%) and variable rate application of lime (78%). The component with the highest rated benefit to cost ratio was the combine yield monitor (4.23 on a scale of 5.0). The highest-rated cost associated with PF adoption was service charges for the variable rate application of lime and or fertilizer (3.36 on a scale of 5.0). Remote sensing data fees were rated as the lowest cost associated with PF adoption (0.33). Since 98% of the sample was not using remote sensing technology, it was therefore rated a very low cost. The highest rated benefit from the adoption of PF was the precise knowledge of soil pH levels in grids and or management zones (4.07). The lowest rated benefit was the reduction in insecticide or fungicide usage (0.25). As for the benefits and costs of the entire PF system adopted, the surveyed farmers are suggesting that the benefits exceed the costs. The average score of all farmers surveyed was 3.76 on a 5.0 point scale where larger numbers indicated increased net benefits of PF. According to the survey results, the most likely management practice to change as a result of PF adoption is the amount of fertilizers or lime applied to fields (4.24 on a scale of 5.0). The least likely to change was pesticide products used (2.52). When asked if they were satisfied with their PF system,

64% agreed or strongly agreed that they were indeed satisfied. No one said they disagreed or strongly disagreed with being satisfied.

Four multivariate regression models were formulated to consider management changes and farmers evaluation of the net personal benefit-cost ratio (BC Ratio). The BC Ratio model suggests that the adoption of a yield monitor alone results in a 0.74 decrease of the BC ratio, however the net effect of both the yield monitor and the GPS receiver is a 0.4 (-0.74+1.14) increase in BC Ratio. This suggests that adoption and use of both components is necessary to achieve a net gain in benefits over costs. A similar result can be drawn from soil pH variability and VRT lime application. In the absence of variable rate lime application (VRT Lime=0), pH variability (uncontrolled) decreases the producers' evaluation of their system (decreases BC Ratio). However, with the ability to manage this variability using variable rate lime application (VRT Lime=1), the producer derives increased value from the overall system as pH variability increases. These results both support a theme that PF provides increased benefits when used in combination. Also, the benefits of PF can be linked to pH variability characteristics and VRT adoption.

The Fertility Management Change model is not statistically significant at the usual critical levels. The adjusted R-squared (-0.02) indicates that the model explains virtually none of the variation in the dependent variable. Only two independent variables are significant in the model, soil variability and Potassium and Phosphorus (PK) variability. The parameter estimate on soil variability is positive and significant at the 10% level. It suggests that as soil variability score increases one unit, the likelihood of fertility management changes will increase 0.28 relative to the average of all other management changes all else constant. PK variability is negative and significant at the

10% level. It suggests that as PK variability score increases one unit, the likelihood of fertility management changes would **decrease** 0.28 relative to the average of all other management changes all else constant. However, the evidence is clear that the model has very little statistical significance. Therefore, any conclusions drawn regarding this model would be statistically questionable.

The Pesticide Management Change model is statically stronger than the fertility model. The results of this model suggest that the model is significant at the 3% level and that approximately 23 percent of the variation in the dependent variable is explained by the model. Further results suggest that as precision farming experience or total acres increase, all else unchanged, pesticide decision changes are less likely to occur than are changes in other management decisions. Also, results indicate that adoption of a yield monitor plus a GPS receiver results in a decrease in the likelihood of changing the pesticide management decisions relative to other management changes. This result may be due to the reasoning that farmers are much more focused on lime and fertility PF and therefore pesticide management changes are less important relative to all other management changes. However, it also may suggest that farmers may have discovered that pesticide decisions are not as important in a site-specific management system as are fertility and planting decisions.

The results of the Planting Management Change model are statistically insignificant. The F value of 1.30 suggests that the model is only significant at the 30% level. Also, every parameter estimate is highly insignificant as well. Therefore, it is not possible to draw any sound conclusions from the existing model. The reason for the lack

of statistical significance could be a result of the use of incorrect independent variables, a poorly defined dependent variable, or a combination of both.

An important overall conclusion can be drawn from the three regression models focused on fertility, pesticide, and planting, management changes. The normalized average scores of all three management changes allowed a comparison to be made across all three. Fertility management changes are the most likely to be changed as a direct result of PF adoption, followed by planting and pesticide management changes. This result was based on the average normalized scores of each management change. Fertility change was the highest at 1.278, followed by planting at 1.016, and pesticide at 0.852 where 1.0 is the average for an individual's response across all categories. Thus, planting decision changes were valued as approximately average in value, lower in importance than the fertility decision, but more likely to be changed than the pesticide decisions.

Overall Conclusions

Several conclusions were supported by both the case study results and the survey results. Similarities involved adoption motivation, PF components adopted, overall benefits, satisfaction, and future outlook regarding PF.

The single most important motivational factor driving PF adoption is to increase profits. A common conclusion is the fact that the farmers want to use the information and data gained from PF adoption to make better informed management decisions thereby increasing their farm business profits.

The most frequently adopted PF components seem to be focused on grid soil sampling and VRT application of lime. However, VRT seeding and pesticide application are lagging far behind the adoption rates of VRT fertilizer and lime. Farmers seem to be much more focused in on PF components that are concerned with soil characteristics. Far less adoption, benefits, and costs are being recognized with PF components that deal with VRT seeding and VRT pesticide application.

The most important benefits from PF adoption seem to stress a more precise knowledge of soil pH, crop yields, and the variability associated with each. Also, both studies support the theme that fertility management changes are the most likely management change to occur as a direct result of PF adoption, as compared to planting and pesticide management changes. Costs associated with adoption seem to be mixed. Neither study supported a similar high cost associated with adoption. Case studies mentioned actual PF component purchasing, while the survey mentioned service charges for VRT application of fertilizer and lime as being the substantial cost factors.

Both studies strongly suggest that farmers who adopt PF are at least satisfied with their PF system they currently use. Overall satisfaction level seems to be above an average satisfied level (>3.0 on scale of 5.0). Also, there is a strong positive outlook for the continued adoption and use of PF in the future. Both studies showed strong indication that farmers will continue to be interested in exploring more PF topics in the future.

Limitations

Limitations exist mostly with the survey conducted through the mail. Since only a small sample of farmers was surveyed, the results lacked statistical power. Expanding the survey to more co-ops and agricultural retailers would increase the sample size dramatically and allow for a more robust and statistically strong analysis. Also, the sample was not random. This limits our ability to make inferences to the larger group of all Ohio precision farmers. Still, the judgment of the researchers is that the membership of this cooperative is likely quite similar to those in most Ohio cooperatives.

Some wording errors were made in a few of the survey questions. This caused some of the data collected to be unusable for this study. Re-wording of a few of the survey questions and clarifying others would result in a more precise survey that is easier to read and interpret.

APPENDIX A

Case Study Questionnaire

Evaluating Adoption and Uses of Precision Farming Technologies

Case Study Questionnaire (12/6/00)

Overview and Goals:

This case study research will be used to develop a clearer and more concise understanding of the adoption and use of Precision Farming Technology and Tools within Ohio. More research within precision agriculture is needed to assist the agricultural community in evaluating the adoption, uses, and the potential management benefits of the technology. Our goal in the study is to better understand the reasons for adoption and the uses of PF information in order to assist growers make the best management decisions they can.

Confidentiality Statement:

This interview will be treated confidentially. Only the researchers, Dr. Marvin Batte and Mr. Mike Arnholt, will have access to data that includes the names of the interviewed farmers. All publication of the results of these interviews will be done in such fashion to shield the identity of the farmers interviewed. In particular:

1. Farmer or business names will not be used in any publication or presentation.
2. Cases will not be identified by county, but only by multi-county district.
3. Any unique activity or feature of the business that is well known and might reveal the identity of the case will not be included in any Extension publication or presentation.

Nature of the Farming Business: ******(I ask these questions and fill in information.)

A. Standard Farm Information sheet on Participants in Case Study Interviews

Name

Address

County

Total years actively farming

Age

Gross sales last year

\$5,001 to 20,000

\$20,001 to 50,000

\$50,001 to \$100,000

\$100,001 to 250,000

\$250,001 to 500,000

\$500,001 to 1,000,000

Over 1,000,000

Fulltime or part time farmer

Highest education level achieved

Total acres farmed

Total acres that are owned

Acres in crops

Raise livestock/crops

Do you currently use a personal computer to assist with your farming operation?

Would you like the results for this study mailed to you?

B. **(I ask these questions and fill in information).

B. Nature of the Farming Business:

How many owners or partners take an active role in the business?

- Who are they?

- a)
- b)
- c)
- d)

- What roles or enterprise responsibilities do they take in the day-to-day operation of the business?

- How large is each enterprise? (acres or # of head)

- a)
- b)
- c)
- d)
- e)

- Are specialized I.P. (identity preserved) commodities produced?

If yes, what are these I.P. commodities?

- a)
- b)
- c)

If yes, are these I.P. grown or sold under contract?

>if yes, are PF tools required by contract?

Factors Motivating Adoption of PF tool(s):

*(I ask these **open-ended** questions, let them talk, and **lastly**, let them rank).

1. Before your adoption of PFT, what agricultural services did you use? ex. soil sampling

*(I need to go to *Before Adoption* sheet to fill out as they talk).

*(Let them RANK factors **last**).

2. Which PF tools have you adopted and currently use? ex. yield monitor

*(I go to *PFT tools* sheet).

*(Let them RANK factors **last**).

3. What were the primary factors that motivated you to adopt PF tools? ex. increase profits

*(I go to *Motivation Factors* sheet)

*(Let them RANK factors **last**).

Uses of the Information Gained from the Entire PFT System:

4. What are the most important pieces of information that you get from your entire PF system? ex. identify weed problems

*(I go to *Uses of Information* sheet).

*(Let them RANK factors **last**).

Management Practices:

*(All are open-ended questions **but** be prepared to prompt with options).

5. Do you use grid soil sampling or some other soil management zone sampling?

➤ If no, Why? (ex. costs, lack of service, etc..)

➤ If yes,

- Who does the sampling?
- Who performs the soil analysis?
- Who makes the fertilizer application recommendations?
- Uniform grids or management zones? (circle one)
- Nutrients tested for?

N
P
K
pH
organic matter
Other micros

6. Do you use VRT application of fertilizers?

➤ If no, why? (ex. Costs, lack of service, etc...)

➤ If yes, which ones?

- N
 - dry
 - liquid
 - anhydrous

- P
- K
- Lime
- Other micros
- _____
- _____
- _____
- _____
- _____
- _____

➤ Who does the VRT application of fertilizers?

➤ If hired, what is the cost per acre?

8. Do you use VRT seeding?

- If no, why? (ex. costs, lack of service, etc.)

- If yes, which seeds? (corn, beans, wheat, other)

- Are you varying hybrid or variety **within** fields?

- Are you varying populations **within** fields?

- Who makes the seed hybrid/variety recommendations?

- Who does the VRT planting?

- If hired, what is the cost per acre?

9. Are there any other PF tools you currently use that we have not discussed?

If yes, please describe them:

*(If farmer is purchasing any of these services VRT, grid soil samples, maps then):
10. How satisfied are you with the Ag. Retailer/Coop service provider on this scale:

- 1= very **satisfied**
- 2= mostly **satisfied**
- 3= **satisfied**
- 4= mostly Dissatisfied
- 5= very Dissatisfied

11. Consider the question of how much phosphorus fertilizer to apply to your crops?

➤ How did you answer this **before** adopting PF tools?

➤ How do you answer it now **after** adoption of PF tools?

12. How have PF tools changed your management practices? ex. planting population

*(I go to *PFT Changing Practices* sheet).

*(Let them RANK factors **last**).

13. a) Have PF tools reduced overall fertilizer application? (yes, no, uncertain)

b) Have PF tools reduced overall pesticide and herbicide applications?

(yes, no, uncertain)

c) Have PF tools produced higher farm average yields? (yes, no, uncertain)

d) Have PF tools decreased yield variation? (yes, no, uncertain)

e) Have benefits of PF tools clearly exceeded the costs? (yes, no, uncertain)

Sources, Satisfaction and Future Goals:

14. How satisfied are you with the overall PFT system that you have used to date?

- 1= very **satisfied**
- 2= mostly **satisfied**
- 3= **satisfied**
- 4= mostly Dissatisfied
- 5= very Dissatisfied

15. Is there any specific area where you think PF could help your specific farming operation that PF is currently not addressing?

16. What has been your single, biggest **disappointment** from the use of PF tools?

17. What has been your single, biggest **success** or **benefit** from the use of PF tools?

***(Ask this question open-ended first, then show grower *Sources* sheet).**

18. What information sources do you rely on the most when you have problems with your overall PFT system?

*(I go to *Sources* sheet).

19. What are your future plans for PFT in the next 1 to 3 years?

*(Depending on their response, be ready to ask the questions below if necessary).

- a). Purchase additional PFT tool(s)
 - If so, which tools will you be purchasing?

- b). Wait to see what new PFT become available.
 - Why are you waiting?

- c). Sell or abandon PFT altogether.
 - Why are you selling or abandoning?

20. Is there anything else you would like to share with us about PFT that we did not ask?

21. If we need to contact you for clarification on a question, what number can we contact you at?

THANK YOU, We appreciate you taking the time to visit with us!!!!

APPENDIX B

Case Study Data Collection Sheets

A. Standard Farm Information sheet on Participants in Case Study Interviews

Name

Address

County

Total years actively farming

Age

Gross sales last year

\$5,001 to 20,000

\$20,001 to 50,000

\$50,001 to \$100,000

\$100,001 to 250,000

\$250,001 to 500,000

\$500,001 to 1,000,000

Over 1,000,000

Fulltime or part time farmer

Highest education level achieved

Total acres farmed

Total acres that are owned

Acres in crops

Raise livestock/crops

Do you currently use a personal computer to assist with your farming operation?

Would you like the results for this study mailed to you ?

B. Nature of the Farming Business:

How many owners or partners take an active role in the business?

Who are they?

- a)
- b)
- c)
- d)

What roles or enterprise responsibilities do they take in the day-to-day operation of the business?

How large is each enterprise? (acres or # of head)

- a)
- b)
- c)
- d)
- e)

Are specialized I.P. (identity preserved) commodities produced?

If yes, what are these I.P. commodities?

- a)
- b)
- c)

If yes, are these I.P. grown or sold under contract?

>if yes, are PF tools required by contract?

1. Before your adoption of PFT, what agricultural services did you use?

(1= MOST important)

Used RANK

- Soil sampling/analysis
- Spraying or application of herbicides
- Spraying or application of insecticides
- Spraying or application of fertilizers
- Custom planting services
- Custom harvesting services
- Scouting for weeds
- Scouting for insects
- Scouting for other crop problems like diseases
- Other _____
- Other _____
- Other _____
- Other _____
- Other _____
- Other _____
- Other _____
- Other _____
- Other _____
- Other _____

2. Which PF tools have you adopted and currently use?

Please rank the tools you have adopted. 1= MOST important tool adopted.

Year Acres
Adopted on Own Hire Rank

Yield monitor

what model name? _____

GPS receiver

what equipment do you use the GPS receiver on?

- a)
- b)
- c)
- d)

GPS backpack unit

Georeferenced scouting for weeds

Georeferenced scouting for insects

Georeferenced scouting for other crop diseases

GIS software or mapping programs

VR application of fertilizer

VR application of herbicides

VR application of insecticides

VR planter or seeder

Arial photography

Infrared photography

Soil grid sampling

what acre size are the grids? _____ acre(s)

how often are samples taken? _____ year(s)

Others not listed

- | | | | | | |
|----|----|----|----|----|----|
| a) | a) | a) | a) | a) | a) |
| b) | b) | b) | b) | b) | b) |
| c) | c) | c) | c) | c) | c) |
| d) | d) | d) | d) | d) | d) |
| e) | e) | e) | e) | e) | e) |

3. What were the primary factors that motivated you to adopt PF tools?

Rank

1 = MOST important

Ranking

Increase profits

Increase market value of owned land

To increase ability to compete for leased land.

Keep clear records for special identity preserved crops

To conduct on-farm experiments

To better comply with environmental laws or regulations

Decrease risk (ex. Yield risks)

Price was right/fair on the PF tools

Project a positive leadership position within the community

Other factor? _____

Other factor? _____

Other factor? _____

Other factor? _____

Other factor? _____

4. What are the most important pieces of information that you get from your entire PF system?

Please rank the following (1= MOST important).

<u>Rank</u>	<u>Types of information/knowledge gained from PF System</u>
	Drainage patterns or problems
	High/low yield areas
	Weed problem areas
	Identity preserved crop records
	Soil Nutrient levels
	Environmental records
	What types of specific records? (ex. fertilizer, pesticide amounts)
	a)
	b)
	c)
	Crop rotation selection
	Selection of crops planted
	Other _____
	Other _____
	Other _____
	Other _____
	Other _____

12. How have PF tools changed your management practices?

Check all your management practices that have changed due to your adoption and use of PF tools.

1 = **MOST** important change

Changed

Rank

- Fertilizer application rate
- Fertilizer application timing
- Pesticide application rate
- Pesticide application timing
- Pesticide product used
- Planting population
- Hybrid or variety seed choices
- Planting timing
 - if changed, is planting time
 - a) earlier
 - b) later
- Crop rotation or selection
- Tillage practices
- Tiling decisions (new, add more, repair, find plugged up)
- Use of field scouting
 - if changed, is field scouting used
 - a) MORE
 - b) less
- Other _____
- Other _____
- Other _____
- Other _____
- Other _____

18. What information sources do you rely on the most when you have problems with your overall PFT system

Rank these sources of information as 1= MOST important.

- Manufacture's customer support phone number
- Manufacture representative
- Local Ag. Retailer
- Extension agent
- Friend
- Instruction manual
- On-Line web site
- Hired Specialist
- Other _____
- Other _____
- Other _____
- Other _____
- Other _____
- Other _____

APPENDIX C

Survey Questionnaire by Mail

We ask that the principal decision-maker of the farm business answer this questionnaire. Please try to answer every question. Select or give the answers that you believe to be most true for your business.

- 1. Did you operate your farm enterprise in 2000? (Circle the correct response) 1. YES 2. NO

If your answer to this question is NO, please RETURN the survey without completing the remaining questions.

SECTION A: Farm Size and Enterprise Characteristics.

- A-1. Of your total cropland (tillable) acreage in 2000, how many acres were owned, rented, etc.? Owned, Rented from others for cash rent, Rented from others for share rent, Rented to others, Total acres operated (1+2+3-4)

- A-2. Please indicate your 2000 acreage of each crop produced. Crop: Corn, Soybean, Wheat (planted 1999), Alfalfa and hay crops, Other crops: 2000 Acreage

- A-3. Did you grow specialty, value-added or identity-preserved crops in 2000? 1. No (skip to question B-1) 2. Yes. a.) How many acres were grown? b.) How many years have you grown specialty, valued added or identity preserved crops?

SECTION B: Precision Farming

For all the following questions, please respond regarding last year (2000) production.

B-1. Did you use georeferenced (i.e., map-linked, or location specific) grid soil sampling? (Circle ONE)

- 1. NO (skip to question B-2)
- 2. YES

a.) Do you use a grid-based sampling approach?

- 1. NO
- 2. YES

→ What size grids? _____ acres.

b.) Do you use a management zone sampling approach?

- 1. NO
- 2. YES

→ What size is a typical zone? _____ acres

How is the management zone identified? (circle ALL that apply)

- 1. Based on soil type
- 2. Based on crop yield map patterns
- 3. Based on soil, pH, or nutrient maps
- 4. Crop Scouting
- 5. Other _____

c.) What year were georeferenced grid soil samples first taken? _____ year

d.) How many of your acres farmed have been grid or zone sampled at least once? _____ acres.

e.) Who did the majority of georeferenced grid soil sampling? (Circle ONE)

- 1. We did on the farm
- 2. Country Star Co-op
- 3. A crop consultant
- 4. Other _____

f.) On my farm, the benefits of georeferenced soil sampling clearly exceed its costs. (Circle One)

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

B-2 Did you use a combine yield monitor to measure crop yields? (Circle ONE)

- 1. No (skip to question B-3)
- 2. Yes

a.) What year was the combine yield monitor first used? _____ year

b.) How many of your 2000 crop acres were harvested with yield-monitored combine? _____ acres

c.) On my farm, the benefits of a combine yield monitor clearly exceed its costs. (Circle One)

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

B-2-A.) Did you also use a satellite GPS receiver with the yield monitor? (Circle ONE)

- 1. No (skip to question B-3)
- 2. Yes

a.) What year was the GPS receiver first used? _____ year

b.) On how many acres was the GPS receiver used in 2000? _____ acres

c.) On my farm, the benefits of a satellite GPS receiver clearly exceed its costs.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

B-2-B.) Did you generate yield, nutrient, pH or other maps for some or all of your fields? (Circle ONE)

1. No (skip to question B-3)
2. Yes

a.) How much time is spent analyzing yield, nutrient, pH and other maps for production problems? _____ hours per year											
b.) Who created the GIS yield, nutrient, pH and other maps? (Circle ONE) <ol style="list-style-type: none"> 1. We did on the farm 2. Country Star Co-op 3. Private consultant 4. Other _____ 											
c.) On my farm, the benefits of GIS mapping clearly exceed its costs. (Circle One)	<table border="1" style="margin: auto; border-collapse: collapse;"> <tr> <td style="padding: 2px;">Strongly Disagree</td> <td style="padding: 2px;">Disagree</td> <td style="padding: 2px;">Neutral</td> <td style="padding: 2px;">Agree</td> <td style="padding: 2px;">Strongly Agree</td> </tr> <tr> <td style="text-align: center; padding: 2px;">1</td> <td style="text-align: center; padding: 2px;">2</td> <td style="text-align: center; padding: 2px;">3</td> <td style="text-align: center; padding: 2px;">4</td> <td style="text-align: center; padding: 2px;">5</td> </tr> </table>	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree							
1	2	3	4	5							

B-3 Did you use georeferenced variable rate application of fertilizers or lime? (Circle ONE)

1. No (skip to question B-4)
2. Yes

a.) Which of the following materials are georeferenced variable rate (VRT) applied? (Circle ALL that apply)												
	Year Adopted	Acres VRT applied in 2000										
1. Lime	_____	_____ acres										
2. Nitrogen	_____	_____										
3. Phosphorus	_____	_____										
4. Potassium	_____	_____										
5. Micronutrients	_____	_____										
6. Manure	_____	_____										
b.) Who is the primary person making the fertilizer/lime recommendations? (Circle ONE) <ol style="list-style-type: none"> 1. We did on the farm 2. Country Star Co-op 3. A consultant 4. Other (specify) _____ 												
c.) On my farm, the benefits of variable application of lime or fertilizer clearly exceed its costs.	<table border="1" style="margin: auto; border-collapse: collapse;"> <tr> <td style="padding: 2px;">Strongly Disagree</td> <td style="padding: 2px;">Disagree</td> <td style="padding: 2px;">Neutral</td> <td style="padding: 2px;">Agree</td> <td style="padding: 2px;">Strongly Agree</td> </tr> <tr> <td style="text-align: center; padding: 2px;">1</td> <td style="text-align: center; padding: 2px;">2</td> <td style="text-align: center; padding: 2px;">3</td> <td style="text-align: center; padding: 2px;">4</td> <td style="text-align: center; padding: 2px;">5</td> </tr> </table>		Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree								
1	2	3	4	5								

B-4 Did you use georeferenced variable rate (VRT) application of herbicides, insecticides or fungicides? (Circle ONE)

1. No (skip to question B-5)
2. Yes

a.) What year did you first use VRT application of the above input(s)? _____ year

b.) How many acres of VRT herbicides, insecticides or fungicides were applied in 2000? _____ acres

c.) Which of the following materials were applied variably? (Circle ALL that apply)

1. Pre-emergence herbicides
2. Post-emergence herbicides
3. Insecticides
4. Fungicides
5. Other (specify) _____

d.) Who is the primary person that makes herbicide, insecticide, and fungicide recommendations for your farm. (Circle ONE).

1. We did on the farm
2. Country Star Co-op
3. A crop consultant
4. Other _____

e.) On my farm, the benefits of variable application of herbicides, insecticides or fungicides clearly exceed their costs.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

B-5 Did you use georeferenced scouting for weed problems, plant disease or insect pest problems? (Circle ONE)

1. No (skip to question B-6)
2. Yes

a.) What year did you first use georeferenced scouting? _____ year

b.) How many acres were scouted using georeferencing in 2000? _____ acres

c.) Who performed the georeferenced scouting? (Circle ONE).

1. We did on the farm
2. Country Star Co-op
3. A crop consultant
4. Other _____

d.) On my farm, the benefits of georeferenced scouting clearly exceed its costs

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

B-6 Did you use georeferenced variable rate seeding (GIS map-based planting)? (Circle ONE)

1. No (skip to question B-7)
2. Yes

a.) What year did you first use georeferenced variable rate seeding? _____ year

b.) On how many acres was georeferenced variable rate seeding used in 2000? _____ ac.

c.) Who is primarily making the seed (hybrid, variety and planting rate) recommendations? (Circle ONE)

1. We did on the farm
2. Country Star Co-op
3. A consultant
4. Seed sales representative
5. Other (specify) _____

d.) On my farm, the benefits of georeferenced variable rate seeding clearly exceed its costs.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

B-7 Did you purchase remote sensing data (e.g., aerial photographs, satellite imagery) for your farm? (Circle ONE)

1. No (skip to question B-8)
2. Yes

a.) What year did you first use remote sensing? _____ year

b.) On how many acres was remote sensing data collected in 2000? _____ acres

c.) On my farm, the benefits of remote sensing data clearly exceed its costs.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

B-8 What were the primary motivational factors behind your adoption of precision farming tools?

(For factors not used, circle 0).

Motivating Factor:	Not a Factor	Motivation				
		Low				High
To increase market value of your owned land	0	1	2	3	4	5
To increase ability to compete for leased land	0	1	2	3	4	5
To better understand individual field variability (fertility ,yield, pH, etc...)	0	1	2	3	4	5
To keep clearer, more accurate records	0	1	2	3	4	5
To comply with environmental laws or regulations	0	1	2	3	4	5
To increase profits by making better management decisions	0	1	2	3	4	5
To decrease risk/risk management	0	1	2	3	4	5
To conduct your own on-farm experiments	0	1	2	3	4	5
To stay on top of current technology available to assist in management	0	1	2	3	4	5
Challenge to try something new	0	1	2	3	4	5
Price was right/fair for the tools	0	1	2	3	4	5
To project a positive leadership role in community	0	1	2	3	4	5
Future use with identity preserved crops	0	1	2	3	4	5
Its fun and I enjoy learning to use the technology	0	1	2	3	4	5
Other _____	0	1	2	3	4	5

B-9. Please rate the variability of each of the following field characteristics for the typical field on your farm. (Circle ONE number per field characteristic).

Field characteristics	Do NOT <u>know</u>	Variability				
		Low				High
Soil types	0	1	2	3	4	5
Soil pH	0	1	2	3	4	5
Drainage	0	1	2	3	4	5
Organic matter	0	1	2	3	4	5
Nitrogen	0	1	2	3	4	5
Phosphorus	0	1	2	3	4	5
Potassium	0	1	2	3	4	5
Slope	0	1	2	3	4	5
CEC (cation exchange capacity)	0	1	2	3	4	5
Crop yields	0	1	2	3	4	5
Other: _____	0	1	2	3	4	5
Other: _____	0	1	2	3	4	5

B-10. Please rate the level of the costs associated with adoption and use of your Precision Farming System. For items that had no cost please circle 0.

Source of Cost	Not a Cost	Cost				
		Low				High
1 Manager time required (including your time)	0	1	2	3	4	5
2 Consulting fees paid	0	1	2	3	4	5
3 Soil sample collection costs	0	1	2	3	4	5
4 Soil testing fees	0	1	2	3	4	5
5 Service charges for Variable Rate Application of Fertilizer/Lime	0	1	2	3	4	5
6 Service charges for Variable Rate Application of herbicides, insecticides and fungicides.	0	1	2	3	4	5
7 Service charges for variable rate planting	0	1	2	3	4	5
8 GPS Equipment and Differential Correction Subscription	0	1	2	3	4	5
9 GIS and Mapping Software costs	0	1	2	3	4	5
10 Computer hardware	0	1	2	3	4	5
11 Remote sensing data fees	0	1	2	3	4	5
12 Input application equipment (spreaders/sprayers/planters)	0	1	2	3	4	5
13 Other _____	0	1	2	3	4	5

B-11 Which of the following have been sources of benefits gained by the adoption and use of your Precision Farming System and how valuable have these benefits gained been? For the benefits that you do not receive, please circle 0.

Source of Benefits	No Value	Value				
		Low				High
1 Reduction in fertilizer usage	0	1	2	3	4	5
2 Reduction in lime usage	0	1	2	3	4	5
3 Reduction in herbicide usage	0	1	2	3	4	5
4 Reduction in insecticide or fungicide usage	0	1	2	3	4	5
5 Identification of drainage problems	0	1	2	3	4	5
6 Precise knowledge of weed problem areas	0	1	2	3	4	5
7 Precise knowledge of soil nutrient levels in grids/management zones	0	1	2	3	4	5
8 Precise knowledge of soil pH levels in grids /management zones	0	1	2	3	4	5
9 Knowledge of where equipment failure may have occurred	0	1	2	3	4	5
10 Quantified and precise knowledge of areas of high/low yields	0	1	2	3	4	5
11 Better knowledge for future selection of hybrids and varieties	0	1	2	3	4	5
12 Better information for crop insurance claims	0	1	2	3	4	5
13 Improved information for crop rotation management	0	1	2	3	4	5
14 Increased ability to compete/negotiate for leased land	0	1	2	3	4	5
15 Reduced soil compaction	0	1	2	3	4	5
16 Better environmental records	0	1	2	3	4	5
17 Increased farm average yield	0	1	2	3	4	5
18 Decreased variability (risk) in yields	0	1	2	3	4	5
19 Other _____	0	1	2	3	4	5
20 Other _____	0	1	2	3	4	5

B-12 For your farm situation, are the total **benefits** of the precision farming system (question B-11) **greater than** the total of **costs** of this system (question B-10)? (Circle ONE.)

1. Yes, Benefits are significantly greater than Costs
2. Yes, Benefits are slightly greater than Costs
3. Benefits and Costs are about equal
4. No, Costs are slightly greater than Benefits
5. No, Costs are significantly greater than Benefits

B-13. Please respond to the following statements about how your precision farming (PF) system may have changed the way that you make the following decisions. (Circle one in each row)

My Precision Farming system has changed . . .	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
the <u>amount</u> of fertilizers or lime that I apply.	1	2	3	4	5
the <u>timing</u> of my fertilizer applications.	1	2	3	4	5
the <u>rate</u> of my pesticide application.	1	2	3	4	5
the <u>timing</u> of pesticide applications.	1	2	3	4	5
the <u>pesticide products</u> I use.	1	2	3	4	5
the planting <u>populations</u> I use.	1	2	3	4	5
the hybrid or seed varieties I plant.	1	2	3	4	5
the <u>timing</u> of my plantings.	1	2	3	4	5
the crop rotation or sequence I follow.	1	2	3	4	5
the tillage practices I use.	1	2	3	4	5
how I make tiling decisions (new tile, tile repairs)	1	2	3	4	5
Other: _____	1	2	3	4	5
Other: _____	1	2	3	4	5

B-14. Please indicate the degree to which you agree or disagree with the following statements. (Circle one in each row)

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I am very satisfied with the precision farming services provided by Country Star Co-op	1	2	3	4	5
I am very satisfied with my precision farming system.	1	2	3	4	5
I believe that precision farming technologies have increased the profitability of my farm.	1	2	3	4	5
I plan to continue adoption of precision farming tools in the future.	1	2	3	4	5
I believe that my crop yields have increased since adoption of precision farming systems.	1	2	3	4	5

SECTION C: E-Business and Strategy

C-1. How much time per week (on average) do you use a computer for the following purposes:

Farm business _____ hours/week (includes _____ hours for e-mail/Internet)
 Personal _____ hours/week (includes _____ hours for e-mail/Internet)

C-2. Who is the primary computer user in your farming operation (circle one)?

- | | | | |
|---|-------------------------|---|-------------------------------------|
| 1 | You – the farm operator | 4 | Hired employee with multiple duties |
| 2 | Spouse | 5 | Dedicated computer/office employee |
| 3 | Child | 6 | Other: _____ |

C-3. Do you use the Internet as part of your farm business (circle one)?

1. Yes
2. No, I don't have a computer
3. No, I have inadequate Internet service
4. No, I have Internet security concerns
5. No, I don't know how to use the Internet
6. No, other: _____

If you do not use a computer, skip to Question C-6.

C-4. How much will you spend in 2001 on computer hardware, software and Internet oriented equipment and services (circle one)?

1	None	4	\$2,501 to \$10,000
2	\$1,000 or less	5	\$10,001 to \$20,000
3	\$1,001 to \$2,500	6	Over \$20,000

C-5. How often do you use the computer for the following in your farm business (circle ONE number per item)?

	Never	Sometimes	Often
Keeping financial records	1	2	3
Keeping production records	1	2	3
Word processing (correspondence)	1	2	3
E-mail	1	2	3
Commodity price tracking on the Internet	1	2	3
Accessing the Internet for other information	1	2	3
Selling your farm products over the Internet	1	2	3
Buying farm inputs over the Internet	1	2	3
Online banking or bill paying	1	2	3
Filing regulatory reports (e.g., pesticide use)	1	2	3
Computerized tax filing	1	2	3
Other: _____	1	2	3

C-6. How important are each of the following as the goal of your farming operation (circle ONE number per goal)?

	Importance				
Goals	Low				High
1. To maximize profitability	1	2	3	4	5
2. To maximize efficiency (i.e., yield per unit input)	1	2	3	4	5
3. To maximize free time for leisure, family, other activities	1	2	3	4	5
4. To preserve the operation to pass on to a son/daughter who farms	1	2	3	4	5
5. To maintain a rural or farming lifestyle	1	2	3	4	5
6. Other: _____	1	2	3	4	5

Of the goals listed above (1-6), which one is (place number in the appropriate box):

<input type="text"/>	Most Important	<input type="text"/>	Second Most Important	<input type="text"/>	Third Most Important
----------------------	----------------	----------------------	-----------------------	----------------------	----------------------

C-7. In terms of the competitive advantage of your farming operation, how strongly do you feel about the following statements (circle ONE number per statement)?

	Strongly Disagree					Strongly Agree				
1. My advantage is that I am a large scale, low cost producer	1	2	3	4	5	1	2	3	4	5
2. My advantage is that I offer a unique or differentiated product/service	1	2	3	4	5	1	2	3	4	5
3. My advantage is that I focus on a certain customer type or segment of customers to buy my products/services	1	2	3	4	5	1	2	3	4	5
4. My advantage is that I have a diversified farming operation	1	2	3	4	5	1	2	3	4	5
5. My advantage is my superior commodity marketing skills	1	2	3	4	5	1	2	3	4	5
6. I've never really thought about my competitive advantage	1	2	3	4	5	1	2	3	4	5
7. Other: _____	1	2	3	4	5	1	2	3	4	5

Of the advantages listed above (1-7), which one is (place the number in the appropriate box):

<input type="text"/>	Most Important	<input type="text"/>	Second Most Important	<input type="text"/>	Third Most Important
----------------------	----------------	----------------------	-----------------------	----------------------	----------------------

- C-8. Think about the competitive advantage that was “most important” to you from the previous question. Which of the following are important to you in maintaining your competitive advantage? (circle ONE number per item).

	Importance				
	Low				High
My ability to purchase additional farmland at an attractive price	1	2	3	4	5
My ability to maintain good relationships with current landlords	1	2	3	4	5
Providing potential landlords with a “menu” of lease types and terms from which to chose	1	2	3	4	5
My ability to lease additional farmland under favorable terms	1	2	3	4	5
My ability to convert current cash leases to share	1	2	3	4	5
My ability to convert current share leases to cash	1	2	3	4	5
My ability to reduce crop input costs per acre	1	2	3	4	5
My ability to reduce fixed costs per acre	1	2	3	4	5
My ability to take advantage of the government farm program	1	2	3	4	5
My ability to maintain a good relationship with my lender(s) to ensure access to credit	1	2	3	4	5
My ability to price my farm commodities at the high end of the market	1	2	3	4	5
My ability to obtain contracts with buyer(s) of my product(s) Using the Internet to sell commodities	1	2	3	4	5
Using the Internet to access markets to sell unique or differentiated products	1	2	3	4	5
Using the Internet to sell directly to consumers	1	2	3	4	5
My own Website (to provide <i>information</i> on my operation)	1	2	3	4	5
My own website (to <i>sell</i> my products/services)	1	2	3	4	5
Accessing information via the Internet	1	2	3	4	5
Accessing decision-making tools on the Internet	1	2	3	4	5
Accessing “communities” on the Internet (e.g., to share ideas)	1	2	3	4	5
Other: _____	1	2	3	4	5
Other: _____	1	2	3	4	5

- C-9. Which of the following management tools/plans do you use in your farming operation (circle yes or no)?

Written business plan	YES	NO
Commodity marketing plan	YES	NO
Cash flow plan	YES	NO
Will	YES	NO
Succession plan for your land/operation	YES	NO
Risk management plan	YES	NO
Written leases for real estate leased <i>from</i> others	YES	NO
Written leases for real estate leased <i>to</i> others	YES	NO
E-commerce/e-business plan	YES	NO
Forward contracting of crops	YES	NO
Futures markets	YES	NO
Other: _____	YES	NO
Other: _____	YES	NO

- C-10. What products or services did you or your family buy over the Internet in 2000 (circle yes or no. If yes, indicate the approximate value)?

Crop inputs (e.g., seed, fertilizer, herbicides)	YES	NO	(\$ _____)
Livestock inputs (e.g., health products, feed, bedding)	YES	NO	(\$ _____)
Grain crops	YES	NO	(\$ _____)
Hay/forage crops	YES	NO	(\$ _____)
Livestock	YES	NO	(\$ _____)
Miscellaneous farm supplies and equipment parts	YES	NO	(\$ _____)
Farm machinery/equipment	YES	NO	(\$ _____)
Personal or household	YES	NO	(\$ _____)
Banking/financial services	YES	NO	(\$ _____)
Information services	YES	NO	(\$ _____)
Other: _____	YES	NO	(\$ _____)
Other: _____	YES	NO	(\$ _____)

Please answer D-9 and D-12 on for the whole business as identified in question D-2

D-9 What was the value of all commodities sold on your farm in 2000 (exclude landlords' share)? Include value of unmarketed (stored) commodities \$ _____

D-10. What percentage of your 2000 farm sales (gross) _____ %
was for livestock products?

D-11. Indicate the range in which your farm business current net worth falls (Circle ONE):

1. Less than \$100,000	4. \$750,000 - \$999,999
2. \$100,000 - \$249,999	5. \$1,000,000 - \$2,000,000
3. \$250,000 - \$749,999	6. More than \$2,000,000

D-12. Indicate the range in which your farm business debt-to-asset ratio currently falls (Circle ONE):

1. Less than 0.15	5. 0.75 - 1.0
2. 0.15 - 0.29	6. More than 1.0
3. 0.30 - 0.49	7. Do not know
4. 0.50 - 0.74	

THANK YOU FOR TAKING TIME FROM YOUR BUSY SCHEDULE TO PARTICIPATE IN THIS STUDY

LIST OF REFERENCES

- Atherton, B.C., Morgan, M.T., Shearer, S.A., Stombaugh, T.S., and Ward, A.D. 1999. "Site-Specific Farming: A Perspective on Information Needs, Benefits and Limitations." *Journal of Soil and Water Conservation*, Vol. 54 (2):455-460.
- Babcock, Bruce A. and Gregory R. Pautsch. 1998. "Moving from Uniform to Variable Fertilizer Rates on Iowa Corn: Effects on Rates and Returns." *Journal of Agricultural and Resource Economics*, Vol. 23(2):385-400.
- Batte, M.T. 2000. "Factors Influencing the Profitability of Precision Farming Systems." *Journal of Soil and Water Conservation*, Vol. 55(1):12-18.
- Batte, M.T. 1995. "Adoption and Use of Farm Information Systems." North Central Regional Research Publication 339.
- English, Burton C., Roland K. Roberts, and David E. Sleight. 2000. "Spatial Distribution of Precision Farming Technologies in Tennessee." Department of Ag. Economics and Rural Sociology.
- Erickson, Kathleen and Lowenberg-DeBoer, Jess editors. 2000. *Precision Farming Profitability*. Purdue University, West Lafayette, IN.
- Hamel, J., S. Defour, and D. Fortin. 1993. *Case Study Methods*. Thousand Oaks, CA.: Sage.
- Kennedy, P. Lynn and E. Jane Luzar. 1999. "Toward Methodological Inclusivism: The Case for Case Studies." *Review of Agricultural Economics*, Vol. 21(2):579-591.
- Kettinger, W., V. Grover, S. Guha, and A. Segars. 1994. "Strategic Information Systems Revisited." *MIS Quarterly*, 18: 31-58.

- Khanna, Madhu, Onesime Faustin Epouhe, and Robert Hornbaker. 1999. "Site-Specific Crop Management: Adoption Patterns and Incentives." *Review of Agricultural Economics*, Vol. 21(2):455-472.
- Lowenberg-Deboer, J. 1999. "Risk Management Potential of Precision Farming Technologies." *Journal of Agricultural and Applied Economics*, Vol. 31(2):275-285.
- Lowenberg-Deboer, J. and Anthony Aghib. 1999. "Average Returns and Risk Characteristics of Site Specific P and K Management: Eastern Corn Belt On-Farm Trial Results." *Journal of Production Agriculture*, Vol. 12(2):276-282.
- National Research Council, 1997. *Precision Agriculture in the 21st Century*. Washington, D.C.: National Academy Press.
- Ohio Department of Agriculture. 1997 *Ohio Agricultural Statistics and Ohio Department Of Agriculture Annual Report*. 1998. The Ohio Department of Agriculture.
- Pierce, F.J. and E.J. Sandler, eds. 1997. *The State of Site-Specific Management for Agriculture*. Madison, WI: American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America.
- Roberts, Roland K., Burton C. English, and S.B. Mahajanashetti. 2000. "Evaluating the Returns to Variable Rate Nitrogen Application." *Journal of Agricultural and Applied Economics*, Vol. 32(1):133-143.
- Sonka, S.T. and K.F. Coaldrake. 1996. "Cyberfarm: What Does It Look Like? What Does It Mean?" *American Journal of Agriculture Economics*, 78: 1263-1268.
- Sonka, S.T., Lins, D.A., Schroeder, R.C., and Hofing, S.L. 1999. "Production Agriculture as a Knowledge Creating System." *International Food and Agribusiness Management Review*, Vol. 2(2):165-178.
- Stake, Robert E. 1995. *The Art of Case Study Research*. Thousand Oaks, CA.: Sage.
- Swinton, Scott M., Stephen B. Harsh, and Mubariq Ahmad. 1996. "Whether and How to Invest in Site-Specific Crop Management: Results of Focus Group Interviews in Michigan, 1996." Department of Agricultural Economics, Michigan State University.
- Swinton, S.M. and J. Lowenberg-DeBoer. 1998. "Evaluating the Profitability of Site-Specific Farming." *Journal of Production Agriculture*, Vol. 11(4):439-446.
- Sunil, Thrikawala, Alfons Weersink, Gary Kachanoski, and Glenn Fox. 1999. "Economic Feasibility of Variable-Rate Technology for Nitrogen on Corn." *American Journal of Agricultural Economics*, Vol. 81:914-927.

Vitosh, M.L., J.W. Johnson, and D.B. Mengel. 1996. "Tri-State Fertilizer Recommendation for Corn, Soybeans, Wheat, and Alfalfa." *Ohio State University Extension Bulletin*, E2567.

Yin, Robert K. 1994. *Case Study Research: Design and Methods*. 2nd ed. Newbury Park: Sage Publications.

