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# IMPROVING FARM MANAGEMENT DECISIONS BY ANALYZING SITE-SPECIFIC ECONOMIC DATA DEVELOPED FROM YIELD MAPS

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ABSTRACT OF THESIS

IMPROVING FARM MANAGEMENT DECISIONS BY ANALYZING SITE-SPECIFIC
ECONOMIC DATA DEVELOPED FROM YIELD MAPS

This thesis examines the use of precision agriculture data, specifically yield maps, for making site-specific economic decisions for improved farm management.  The adoption of precision agriculture on farms has allowed producers to collect a greater quantity and more specific information about production than ever before.  With such information, site-specific decisions can be made.  Incorporating economic data with yield map data, two primary decision examples are developed: defining areas of production and nonproduction and managing temporal risk spatially across a field.  Included with the production/ nonproduction decision are the effects that land tenure arrangements and risk aversion levels have on the decision.  The risk maps are developed using break-even analysis, the coefficient of variation, and a mean-variance framework, all based on a twenty year average of temporal net returns, measured spatially.  The risk maps are repeated incorporating a crop insurance option, a commonly used risk management tool.  Results show that developing these maps can be used by agricultural producers to help with their decision making.  By incorporating these maps into the decision-making process, decisions can be made to increase farm profitability.

KEYWORDS: Precision Agriculture, Farm Management, Risk Aversion, Decision Making

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Laura A. Powers

November 22, 2002
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IMPROVING FARM MANAGEMENT DECISIONS BY ANALYZING SITE-SPECIFIC
ECONOMIC DATA DEVELOPED FROM YIELD MAPS

By

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November 22, 2002

RULES FOR THE USE OF THESES

THESIS

Laura Ann Powers

The Graduate School

University of Kentucky

2002

IMPROVING FARM MANAGEMENT DECISIONS BY ANALYZING SITE-SPECIFIC
ECONOMIC DATA DEVELOPED FROM YIELD MAPS

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THESIS

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A thesis submitted in partial fulfillment of the
requirements for the degree of Master of Science in the
College of Agriculture
at the University of Kentucky

By

Laura Ann Powers

Lexington, Kentucky

Director: Dr. Carl R. Dillon, Associate Professor of Farm Management

Lexington, Kentucky

2002

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"The man who removes a mountain begins by carrying away small stones." This Chinese proverb sat on my desk throughout the duration of my research. This thesis would not be complete without acknowledging all of those that helped me in removing those stones. It has not been the work of one individual, but many, that have made the completion of this thesis reality. My parents taught me that when someone helps you, you say "thank you". This is my opportunity to do just that. The first and foremost "thank you" goes to God. He has given me the perseverance and strength to see this project through. Without His blessings, none of this would have been possible.

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It has been through the contributions and efforts of all of these individuals that has brought about the completion of this thesis. I am a very fortunate person to have had such wonderful sources of support and guidance through these last few years. Together, we have moved that mountain.

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# Chapter One
## Introduction and Review of Literature

## Introduction

In the early 1900's, the structure of agriculture faced changes from the then newly developed technology of tractors. The initial efficiency of tractors on the farm was questionable. It was not until farmers gained experience with farm machinery that the use of tractors became a positive influence on the structure of agriculture (Lowenberg-DeBoer 1996). Now, it is difficult to imagine a farm without the use of tractors, combines, and other mechanized machinery.

Precision agriculture (PA) is a technological change in production agriculture with the potential to alter management strategies on the farm. Agricultural producers have long been aware that productivity varies within fields. Until recently however, producers have been unable to accurately measure this spatial variability. With the advent of PA, agricultural producers are now able to quantify this variability and manage their farms accordingly.

PA, also commonly referred to as site-specific management or prescription farming, is a broad term for a developing technology. Briefly, PA is information technology applied to agriculture (Lowenberg-DeBoer and Boehlje). Information technology, in terms of PA, refers to the methods and abilities of the agricultural producer or researcher to collect and geographically reference data as they move across the field. The basis for PA is that it allows for the study of fields on a much finer resolution. Rather than collecting and analyzing data on a field by field basis, farm data can now be collected and analyzed at the sub-field level.

The overall purpose of this thesis is to examine the use of PA data to make strategic decisions for the farm business. Specific objectives are:

1. Develop the economic framework and model to identify production and non-production areas within a field, as well as how a producer's aversion to risk and land tenure arrangement affects the size and shape of these areas,

2. Identify statistical measures of risk that can be used to create risk maps which visually depict temporal changes of risk within a field spatially, and

3. Provide empirical applications and interpretations of the resulting maps from each of these articles.

These objectives will be reached through the writing of two scientific articles. Although these articles will be separate pieces, they will compliment each other through a common theme. This common theme is the use of PA data for improved decision making on the farm. A more thorough

justification of this format will be presented later.

Using PA data to make farm decisions was chosen as the topic of this research because of its importance for improved farm management and the fact that it has largely been neglected in previous PA research. As will be discussed in Chapters Two and Three, the area of decision making using PA data has been identified as a weakness in PA literature. The ultimate reason for collecting information is to use it to make good decisions. Users of PA collect a great deal of information, and for several years many producers have been collecting this data and doing very little with it. For PA to fully become an agricultural management system, that data must be used to make profitable farm decisions. This research is an initial attempt at closing the loop between information and decisions.

The remainder of this chapter will further introduce the concept of using PA data to make strategic farm decisions. While each of the two articles will include their own review of the relevant literature, this chapter will discuss the general literature for PA and decision making. This review of literature will begin with the discussion of farm management and decision making.

## Farm Management and Decision Making

This section will present the evolution of farm management and the development of decision-making tools within the field. Tools such as the decision-making acronym RADAR, marginal analysis, partial budgeting, and break-even analysis will be discussed.

The evolution of farm management revolved around clearly defined principles, with the central principle based upon profit maximization for the farm business (Jensen; Martin; Heady and Jensen). Making, implementing, and bearing the responsibility of decisions are the foundations for profit maximization in Forster and Erven's definition of farm management. According to Heady and Jensen, "the greatest returns in farming are to be had from 'brain activity' rather than 'brawn activity'" (p. 16). In other words, although a large part of farming is the implementation of production practices, i.e. planting, harvesting, or feeding livestock, the "greatest returns in farming" are from activities such as making (and implementing) decisions.

Many studies have outlined the elements for healthy decision-making skills, because of their importance for the farm business. The pioneering work that added the dimension of decision making to the science of farm management was Johnson and Associate's Interstate Managerial Study in 1961. Soon thereafter, many other studies outlined and analyzed the elements for the decision-making process (Brannen, Routhe, Tedford, Langham). Those elements are "to define problems, to identify and assemble relevant information, to specify alternative possible solutions, to decide on

and take action, and to evaluate the performance of all of these functions" (Jensen, p. 60).

The fundamentals for decision making have not changed over the years. Using the same elements as the above studies, a framework was developed for students of farm management to learn the principles of decision making. In making good decisions, using the acronym **RADAR** includes the necessary steps: **R**ecognize the problem or opportunity, **A**nalyze among the alternative options, **D**ecide among the alternatives, take **A**ction, and bear **R**esponsibility for those actions (Isaacs and Trimble). While this process may be shorter or longer for different decisions, all of the steps must be taken (Forster and Erven).

As the field of farm management changed into one of problem solving, economic decision-making rules were developed to aid this transformation. Marginal analysis has become one of the most basic methods for deciding on the best level of input or output of production. Marginal analysis measures the marginal, or additional, value of output and compares it to the marginal cost of producing that output. Specifically, the decision-making rule is to seek the production level where the marginal cost (MC) of production equals the marginal revenue (MR) for the enterprise. (Kay and Edwards).

The partial budget is a commonly used decision-making tool, which looks at incremental changes in the farm business (Forster and Erven). A partial budget is different than the typical enterprise or whole farm budget in that it does not incorporate every cost associated with an enterprise or farm. The primary advantage for employing partial budgets in decision making is their simplicity. For example, in the production and non-production decision, an entire field budget would have to be developed for each scenario to make the decision. However, when applying partial budget concepts, a single budget is created which includes those costs and revenues that would be affected if a change (removing areas from production) were to occur. A partial budget compares the advantages (additional revenue plus reduced costs) and the disadvantages (reduced revenue plus additional costs) to make a decision with a net advantage. If the advantages equal the disadvantages, the manager would be indifferent between the two options, signifying the break-even point of the decision.

Break-even analysis is another commonly used decision tool in farm management. Similar to partial budgeting, break-even analysis calculates the minimum level of output or input to justify production. A common break-even analysis example in agricultural production is calculating break-even yields (output levels). Variable costs are divided by an expected price received for the crop to calculate break-even yields, as in Equation 1.1:

Equation 1.1)  Break-even Yield  =  (Selected Costs)/(Expected Price)

The answer gives the minimum production level required to cover the specified costs at the expected price.  Break-even yields are typically calculated using either variable or total costs.

The literature on break-even analysis demonstrates its usefulness as a farm management tool. Break-even analysis has been used in the calculation of the maximum level of an input price (diesel fuel) one would pay to break even (Dillon and Roberts), calculation of break-even points among enterprises (Dillon 1992), break-even planting and harvesting decisions (Dillon 1994), and the elasticity of break-even prices between enterprises (Dillon and Casey).  Other studies have demonstrated break-even analysis as a decision rule (Pearce et al.; Roberts, Pendergrass, and Hayes). Roberts, Pendergrass and Hayes demonstrated the use of break-even analysis as a decision criteria in studying the economics of Roundup Ready (RR) soybeans.  They concluded that if the producer did not expect to receive a conventional yield greater than the break-even yield found with RR soybeans, the producer should switch to RR soybeans.

The preceding section outlined various economic tools available to agricultural producers for making sound economic decisions.  As stated earlier, for a farm manager to maximize profits, sound decision-making skills are necessary.  One of the steps in making decisions is collecting and analyzing information about the decisions to be made.   The next section will discuss the role that PA has in farm business decision making through its abilities to collect and analyze information.

## Precision Agriculture

As previously stated, the advent of PA has introduced new tools for farm management.  The development of PA technologies has provided the ability to collect and analyze a substantial amount of site-specific farm data.  This section will provide background information on PA and explore the multifaceted areas of research involved in its development.

### Background

An early adopter of PA in Minnesota claimed that this site-specific information " 'isn't making farming easier; it's just changing the way we do things' " (Gibbons, p.2).  Many researchers have tried to label PA as being a revolution, evolution, or simply a dead end (Lowenberg-DeBoer 1996).  Although the technologies are no longer in their infancy, they are still being developed.  Time will tell how they will affect the business and structure of agriculture.

PA is most commonly thought of as the individual technologies which are a part of the

larger system. The Congressional Research Service (CRS) has defined PA as "a suite of technologies that use sensing and geo-referencing innovations to apply more precise inputs based on a field's biophysical variability" (CRS, p. 1). The National Research Council outlines these technologies as remote sensing, global positioning system (GPS), geographic information systems (GIS), and process control. These four technologies work together to allow the producer to collect, analyze, interpret, and then use the information to make sub-field rather than field or farm level decisions (Batte). Remote sensing technologies, such as yield mapping and soil nutrient sensors, allow the producer to locate stresses in the field. GPS consists of a network of satellites that enable an end-user with a receiver to determine the longitude, latitude, and elevation of the location of in-field stressors. GIS packages store, manipulate, and display the collected spatial information. Process control technologies use GIS information to "control the processes" of variable rate applications, such as for fertilizer, seed, or chemicals.

However, PA is more than the individual technologies. It is a system that can be used for farm management. The Congressional Research Service concisely defines PA as a "high-technology agricultural management system" (CRS, p. 1). A common way of viewing PA is by the information collected and how that information is applied to agriculture (Lowenberg-DeBoer 1996; Watermeier; Jerome and Gilbert). In short, PA uses information technology to help make decisions throughout all aspects of the farming system.

Because PA affects the entire farming system, many agricultural disciplines, especially economics, engineering, and agronomy, have been involved in its research. For simplicity, the discussion of the relevant literature for PA will be divided into three categories: general, non-economic and economic. The discussion will begin with the general category.

### General Precision Agriculture Studies

While much research has focused on specific PA technologies, which will be discussed in later sections, a number of publications have provided general information on these systems. Research in the area of PA has discussed its history and "basics" (Congressional Research Service, USDA 1998), the state of the technological systems (Stombaugh et al., National Research Council, Reid, Gibbons, Clark), and how PA may change the future of agriculture (Clark; Lowenberg-DeBoer 1996; Lowenberg-DeBoer and Boehlje). While there has been general discussion on decision making and information needs in PA (Watermeier; Atherton et al., Fleming et al.), the need for decision-making tools has been identified as a shortcoming in the literature (Gibbons, Atherton et

al., Lowenberg-DeBoer 1996). Lowenberg-DeBoer (1996) claims that the lack of decision support has been a factor in low adoption rates of PA.

General information on PA has been collected through surveys in states and regions which have become involved with PA. The literature on adoption includes Kentucky (Shearer et al.), Michigan (Swinton, Harsh, and Ahmad), Tennessee (English, Roberts, and Sleigh), Arkansas (Griffin, Oriade, and Dillon), Mississippi (Hudson and Hite), Argentina (Lowenberg-DeBoer, 1999a), the Midwest (Daberkow and McBride; Lowenberg-DeBoer 1998), and the north central United States (Khanna, Epouhe, and Hornbaker). Adoption of PA in the United States in general has also been discussed by Khanna, Epouche, and Hornbacker as well as Lowenberg-DeBoer (1998). In addition, a survey by Daberkow and McBride questioned corn producers in sixteen states (including Kentucky) about their adoption of PA. The most prevalent technology used in these areas was either grid soil sampling or variable rate application.

In 1998, Shearer et al. surveyed Kentucky producers on their use and intentions of PA technologies. The survey collected grower information from 1994 through 1998. Out of the nearly 90% of respondents that had implemented some technology of PA, yield monitors were the most prevalent. Increasing from 1,462 acres (from two out of 37 producers) in 1994, yield monitor use rose to 46,030 acres (from 25 producers) in 1998. Yield monitoring was also considered the number one technology expected to increase farm profitability. In addition, those surveyed responded that they expected PA use to increase. From the time of the survey through 2005, participants claimed they intended to more than double their use of PA technologies.

**Non-Economic Studies**

While the focus of this research centers on economic decision making of PA information, one would be remiss not to at least briefly discuss the non-economic PA research. The individual on-farm uses of precision technologies has been the focus of many research studies. Although many advances of PA technologies have occurred, only the most prevalent will be discussed here.

As previously stated, many producers are introduced to PA through the use of yield monitors. Shearer et al. (1999) discussed the fundamentals of yield monitoring from purchase considerations to operation and correction. In Shearer et al. (1997) fundamentals of yield monitoring systems are outlined. The authors explain that the process of generating yield data is not achieved through only a yield monitor, but through an entire system of devices, including a "grain mass-flow or volumetric flow sensor, moisture sensor, ground speed sensor, data storage device, an

integral user interface, and a control box" (p. 3).

Although a large amount of data can be collected through the yield monitoring system, this data is often not without error. Sources of error include poorly calibrated yield monitors, method of moisture sensing (i.e. buildup or accumulation of plant residue on the sensing plate), ground speed calibration, and effective header width (Shearer et al. 1999). Other errors may be introduced when using multiple harvesters. Electronic devices, such as cellular phones and CB radios, may also cause interference (Lotz). Chapters Two and Three will discuss the framework for removing errors in yield monitor data.

While a yield monitor helps to identify variability in yield within a field, it may also aid in identifying the cause for low producing areas (Lark and Stafford). Patterns of variance may be either straight lines or irregular (Lotz). Straight lines are typically caused by human interference and either with or against the direction of application. Straight line patterns in the direction of application include a change in planting date or variety, chemical misapplications, or compaction. Straight line patterns against the direction of application include tiling, underground lines, or historically different fields. Irregular patterns may be in the form of an irregular line or an area or patch. Irregular lines may be the result of chemical drift or waterways. An irregular area or patch may evolve from change in soil type, insects or diseases, animal damage, or previous crop activity.

A technology that has been developed to match inputs with variable field conditions is variable rate technology (VRT). VRT has become a popular precision technology because it fits easily in current crop production systems (Engebretson). VRT research is available for general information (e.g. Clark and McGuckin) and for specific crop responses (Redulla et al., Ferguson et al.). The potential exists for site-specific fertilizer application to decease fertilizer costs, reduce the environmental impact, and promote more consistent grain quality (Doerge). However, this potential depends on the variability of fertilizer needs in the field (Everett and Pierce).

The use of yield maps and VRT are a starting point for making decisions. Agricultural producers generally make decisions that they hope will have a positive influence on farm profitability. The next section begins the discussion on the economic studies for PA, of which a majority have focused on the potential profitability of the technologies.

**Economic Studies**

Since the advent of PA, producers and researchers have questioned the profitability of the technologies. The most common form of profitability analysis of PA has been the partial budget

(Engebretson). As previously stated, the partial budget is used to analyze a potential change in the business. The decision to invest in precision technologies is a decision to make a change in the farm business.

The most comprehensive review of PA profitability studies came in 2000, by Lambert and Lowenberg-DeBoer. They summarized 145 studies, of which 73% were VRT related. Of the 108 studies that reported economic results, 63% reported positive economic benefits, 26% reported mixed results, and 11% reported no economic benefit. In short, profitability for site-specific management has shown to be just that, site-specific.

Although individual precision technologies have not always proven profitable, one cannot draw the conclusion that PA is not always profitable. With many technologies, such as VRT, the changes in costs and returns are more easily quantified. However, many commonly used precision tools, such as mapping, only collect information. Information, on the other hand, is not as easily valued. According to the Engebretson, "information increases profitability only through changed decisions. If information changes decisions and these decisions are more profitable than those that would have been made without that information, then the increase in profit is attributable to the information" (p. 38). So the question to be addressed is how do producers make decisions from information collected from PA.

Yield maps are one of the most common outputs generated from PA. These maps quantify the spatial yield variability within fields, confirming what producers have known. While profitability is one of the main goals of a producer, yield maps identify productivity. Yield maps can therefore be adjusted to generate a visual depiction of temporal changes that have occurred, on a spatial basis. A variety of measures can be used to create these maps. For example, if coupled with selected expenses, yield maps can be adjusted to generate net returns maps, showing those more and less profitable areas within a field. Furthermore, net returns maps can be further modified to calculate risk statistics. These risk maps can be used to map changes in temporal risk spatially. Producers can then use these maps to make profitable decisions. Thus, if decisions are made with profitable results from yield map data, mapping can be a profitable output of PA.

## Factors Influencing Decisions

The decisions made with the various maps created with PA data can become even more useful when incorporating other factors that influence farm decisions. These factors can be included in decision maps as long as there is a way to measure or value them. This section will identify two

key decision influences, risk and land tenure arrangements, that will be incorporated into these decision maps.

One of the biggest influences in agricultural decision making is risk. Agricultural producers face risks every day, including pests, diseases, crop prices, weather and injury. Although consideration of all of these risks are important to the farm business, production risk will be the key focus for this research. The decisions that a farmer makes are based on the amount of risk they are willing to bear, which varies from one farmer to another.

Although land tenure arrangements may also be used as a risk management tool, the decision to enter into these arrangement contracts also affects a farmer's decisions. The landowner and the producer may have common or divergent interests, depending on the tenure arrangement (rented, crop share, or cash share). For example, in cash rent arrangements, the landowner is typically more interested in the long term sustainability of the land. However, unless they have a long term contract, the producer is primarily concerned with only the current production year. However, in either crop share or cash share, both parties have an interest in crop productivity. A number of studies have examined the development of land tenure contracts between landowners and producers, including how both parties can maximize wealth (Allen and Lueck) and how they can maximize utility (Braverman and Stiglitz).

Tenure arrangements are one method producers have for managing risk. As previously stated, both parties have an interest in how well the crop produces in crop and cost share arrangements. Thus, some of the risks associated with crop production, such as commodity prices and yields, are shared by each party. Consequently, risk and land tenure arrangements display interactive consideration in influencing the farmer's decisions. Additional literature regarding risk and land tenure arrangements will be presented in Chapter Two.

## Chapter Initiatives

Chapter One has introduced the idea of using PA data to make economic farm management decisions. It has also outlined general literature relevant in this decision-making process. These ideas will be put into action in Chapters Two and Three. Each of these chapters are stand alone articles, complete with their own objectives, literature review, methods and conclusions.

Chapter Two will establish the framework for users of PA technologies to make decisions from yield monitor data. The example decision will be to identify areas within fields where, based on break-even analysis, a producer may chose not to produce. The effects of the producer's

aversion to risk and land tenure arrangements will also be included.

Chapter Three will again use yield monitor data for economic decision making and will be a stand alone article on the development of risk maps. It will use break-even probabilities, coefficient of variation and a mean-variance framework with net returns to identify spatial changes in temporal risk across a field. These risk maps will be repeated to include a crop insurance option to examine if decisions would have been different had the farmer used crop insurance over the production history.

Chapter Four will present the conclusions for this research. It will provide a summary of the previous chapters and offer insights for future research areas. This chapter will also briefly discuss the possibility of an economic advisory service which will offer producers the means of developing maps for their farms.

## Approach

This author believes that some justification is needed given the non-typical format of this thesis. As previously discussed, this thesis presents a series of scientific articles. While these articles have a similar theme, they are separate research topics. The benefits to a two article thesis is that is allows for easier submission of the research for conferences and journals. For example, the results from Chapter Two were a selected paper for the Southern Agricultural Economics Association meeting, part of selected posters for the American Agricultural Economics Association and Sixth International Precision Agriculture meetings, and a newsletter article, all before Chapter Three was completed. The down side to this format is that there is some repetition within the thesis. Nevertheless, the benefits for writing the thesis in this format outweigh the disadvantages.

An additional deviation of this thesis from others is its exclusion of a separate literature review chapter. Again, because of the two article approach, each of the articles has their own literature review. With the similar theme between the two chapters, some sections of the articles that were repeated between them. Rather than replicating the additional literature from the article chapters in yet another chapter, the general literature relevant to the thesis, but not necessarily to the articles, was included in this introductory chapter.

# Chapter Two

## Development of a Decision-Making Advisory Framework for Users of Precision Agriculture: A Production/Nonproduction Decision Example

### Introduction

Making good farm management decisions depends on the farmer's ability to collect quality information. With the advent and increased use of precision agriculture (PA) technologies over the last several years, farmers have gained the ability to collect more site-specific information than ever before. Rather than collecting and analyzing data on a field by field basis, data can now be collected and analyzed at the sub-field level. A popular method for collecting information with PA is through mapping, as identified in a 1997 survey of Kentucky producers by Shearer et al. (1999). They discovered that the majority of respondents used PA to create yield (88%) and field (73%) maps.

One of the first economic questions regarding PA was, "is it profitable?" The most recent collection of PA profitability studies was completed by Lambert and Lowenberg-DeBoer in 2000. Of the 108 studies that reported economic results, 63% reported positive economic benefits, 26% reported mixed results, and 11% reported no economic benefit. In short, the profitability of site-specific farming was just that, site-specific. While some farmers realized profits using precision technologies, others have not. Thus, if profitability for PA technology is uncertain, how will farmers determine if PA will be profitable?

Ultimately, the answer to the question of profitability lies in how PA is used to make decisions on the farm. Users of precision technologies collect a wealth information. Users of practices such as VRT collect information on changes in specific production expenses, such as fertilizer, pesticides, or seed, within a field. Users of yield monitoring collect information on the changing yield levels throughout a field. The information provided through these technologies help producers make those tactical decisions within each production year. The next step in the decision-making evolution of PA is to develop the strategic, or long term decision-making skills.

One such strategic decision is identifying areas within a field that a producer might remove from production for economic reasons. By combining the spatial productivity measures of yield maps with cost information (identified spatially or not), maps can be created which identify areas of higher and lower profitability throughout a field. These maps have been commonly referred to as profit maps, however this is not technically correct. Profit is the return after all costs have been

subtracted from gross returns. Typically however, only selected costs are included in the maps. Thus, these maps will be referred to as net returns maps, which allow the producer to identify those areas which have historically not covered costs. The producer can make their decision to remove those areas from production. This research will address procedures for developing such maps and identify factors which may influence the decision.

One influential factor in identifying areas of production and nonproduction is the level of risk a producer is willing to accept. A net returns map can be adjusted by a risk aversion parameter and the variability of net returns to develop a risk adjusted net returns map. These maps can be created according to different levels of risk aversion (neutral, low, medium and high), reflecting the varying risk attitudes of producers.

Land tenure arrangements are one method producers use to manage risk. Increasingly, Kentucky land is being farmed by those who do not own it. In 1988, 23% of agricultural land was rented, and by 1999 the percentage of land increased to 30% (USDA 1999). Three common land tenure arrangements exist among farmers and landowners: cash rent, crop share and cost share. Perspectives of both the landowner and producer must be incorporated into risk analysis, because of the unique risks faced by each participant. Thus, a producer or landowner can identify areas of the field with greater levels of risk given their land tenure perspective and incorporate these factors into their negotiation decision making.

This study evaluates data provided by a cooperating grain farmer in western Kentucky. Using yield monitor data from a 124 acre corn field, a net returns map will be generated. The net returns map will be modified by various risk aversion levels (low, medium, and high) to create a risk adjusted net returns map. Tenure arrangements will be included in both maps to determine the effects they have on the production/nonproduction decision. The following tenure perspectives will be considered: owned land, cash rent (producer), crop share (landowner and producer), and cost share (landowner and producer). Because of the partial budget, or more generally, marginal economic analysis approach of this study, only the producer's position will be analyzed for the cash rent situation. For rented land, the landowner is paid a fixed per acre rent on the land. If the producer does not produce on all areas of the field, the amount paid to the landowner would not change. Thus, the landowner's perspective on rented land will not be examined.

This study is a beginning step in providing producers with the ability to make decisions from PA data. Although the next section will further discuss the current literature (or lack thereof) regarding decision tools for users of PA, in short, this has been a relatively unexplored area.

Decision aids such as these will provide a means through which producers can close the loop between adopting the technologies and using them to make more informed decisions to improve farm profitability.

It should be noted that this study will not provide answers for whether or not producers should remove land from production. The identification of potential nonproduction areas is only the first step in this decision process. Several options are available should producers choose to act on the information. First, producers may choose to profitably correct those unprofitable areas. Secondly, producers will have to decide which areas to remove from production. They will have to compare the ease of not producing on unprofitable areas versus the monetary loss from their production. For example, while producers may produce on unprofitable grids scattered within the field, field boundaries or larger contiguous sections within the field may be more easily taken out of production.

The primary purpose of this research is to provide producers tools from which they can make economic decisions from yield monitor data. Specific objectives are: 1) develop the economic framework and model for the produce/no produce decision, coupled with how the producer's aversion to risk and tenure arrangements may affect this decision, 2) establish the procedure for implementing this process, and 3) provide an empirical application and interpretation of the resulting net returns and risk adjusted net returns maps.

This research uniquely adds to the current body of literature in a variety of ways. Primarily, this research is an initial step in providing PA adopters with an economic use for yield monitor data. Heretofore, the use of PA data for decision making has largely focused on seasonal production decisions, such as variable rate applications. Thus, this research widens the usefulness of PA data for making strategic farm decisions in long term planning, as opposed to the more traditional tactical or short run decisions. This research also allows for simultaneous comparison of land tenure arrangements and risk aversion levels.

**Theoretical Framework**

The first step in establishing the process for developing a production/nonproduction decision aid is outlining the theoretical framework for making such decisions on the farm. Such discussion will be presented here, beginning with a presentation of marginal economics as well as break-even and partial budget analysis. Following will be an outline of the relevant theory on risk as it pertains to the production/nonproduction decision, as well as how land tenure arrangements

affect the decision.

One of the most important roles of the farm manager is making decisions. The primary farm production decision is whether or not to produce. Information about the costs and returns for enterprises are necessary for making such decisions. In traditional agriculture (without PA), information was collected and analyzed based on total crop expenses and yields. Although it has long been known that soil characteristics vary across a field (Schnitkey, Hopkins, and Tweeten), causing a subsequent spatial variation in crop productivity, traditional agriculture has not provided the ability to accurately measure this spatial variability. With the advent of PA, producers now have the ability to collect and analyze information on much smaller units, such as 1,076 ft$^2$ grids, within fields. This information can be used to identify areas within a field that may removed from production.

The underlining theory behind this research is that while agricultural producers are achieving maximum profitability given their constraints in collecting information, profitability can be improved by their using site-specific cost and return information. In choosing the profit maximizing level of production, economic theory dictates that it is at the point where marginal revenue equals marginal cost. In traditional agriculture (without PA), this equality is observed at the field level in terms of average variable cost and average returns. Farmers find it difficult, if not impossible to measure marginal cost and marginal returns at the field level. When precision technologies are applied and the field is divided into grids, the "average" profit maximizing output level calculated at the field level will differ from that of each individual grid. Applying the field-level optimal output to each individual grid will result in some grids producing above the profit maximizing output level and some below. Thus, removing grids whose marginal cost exceeds marginal revenue improves the profitability of the entire field.

This economic theory is applied on the farm by comparing the value of yield to the cost of production. Production of a given area is justified when the returns generated by the area are greater than its variable costs. As discussed earlier, a commonly used PA technology, yield monitoring, collects yield information for individual grids throughout a field. When coupled with expense information, grids that do not cover variable costs can be identified. These areas can then be removed from production. The specific decision tool to discriminate between areas of production and nonproduction is the partial budget.

Partial budgeting is used for a proposed change to the farming structure, such as moving areas out of production. Only those costs affected by the decision, such as seed, chemicals, and

fertilizer, are included in this partial budgeting analysis. By comparing the advantages (additional revenue and reduced costs) to the disadvantages (reduced revenue and additional costs) of a decision, the producer will make the decision resulting in a net advantage. Partial budgeting has been used in several PA studies, including ownership of precision equipment (Gandonou et al.) and enrolling buffer strips into the Conservation Reserve Program (CRP) (Stull et al.). In Lambert and Lowenberg-DeBoer's analysis of PA profitability studies, 69 out of 108 documents used either a partial budget or a rough partial budget analysis.

Similar to partial budgeting, break-even analysis, "calculates the minimum benefit required from an activity in order to justify making the change" (Calkins and DiPietre, p. 146). Break-even analysis literature demonstrates its usefulness as a farm management tool. The most basic form of break-even analysis calculates either the yield or commodity price to be received, given selected costs, to generate a return of zero dollars. This foundation is presented in many basic farm management textbooks (e.g. Kay and Edwards). Break-even analysis has also been extended for further analysis. Examples include the calculation of the maximum level of an input price (diesel fuel) one would pay to break even (Dillon and Roberts), calculation of break-even points among enterprises (Dillon 1992), break-even planting and harvesting decisions (Dillon 1994), and the elasticity of break-even prices between enterprises (Dillon and Casey). Computerized budgets, such as the Harvest Decision Aid (Isaacs, Dillon, and Powers) and the Roundup Ready Beans Decision (Isaacs and Powers) are also available to make break-even analysis and decision making easier.

When making production decisions, producers must also consider the associated risk. The pioneering of risk and decision theory began with the game theory work of Von Neumann and Morgenstern. It was their seminal work which dictated that the decision maker uses expected utility to make their "best" choice (Day). In making decisions, one must chose among a set of alternatives with varying degrees of risk and a set of probability distributions. Their decision is based on finding the alternative which maximizes their expected utility (Freund).

The next step in the evolution of risk theory provided that rather than looking at all probabilities, decisions were based on two statistics, the mean and variance of the models (Varian; Boisvert and McCarl). The development of E-V analysis began with Markowitz in his analysis of investment strategies (Varian, Young). The E-V model states that decisions are made using the mean and variance of net returns, preferring a higher mean and lower variance. It has been found that E-V analysis is a proper tool to use, as being consistent with expected utility modeling, when the stochastic variables differ only by location and scale (Meyer) such as when returns are normally

distributed (Boisvert and McCarl). The framework for the E-V model is as follows:

$$\text{Equation 2.1.) Max: } EV = \sum \bar{r}_i * x_i - \Phi * Var_y$$

where EV is the risk adjusted net returns, $\bar{r}_i$ = average rate of return, $x_i$ = dollars invested, $\Phi$ = risk aversion parameter, and $Var_y$ = variance of net returns.

The difficulty with this approach is that the risk aversion coefficient (RAC) must be known. McCarl and Bessler developed an approach to calculate a level of risk aversion when the utility function is not known. Their formula for calculating RACs is as follows:

$$\text{Equation 2.2.) } \Phi = \frac{2Z\alpha}{S_y},$$

where $\Phi$ = the risk-aversion coefficient, $Z_a$ = the standardized normal Z value of $\alpha$ level of significance and $S_y$ = the relevant standard deviation. The resulting RAC, when applied to equation 2.2, gives the level at the which the producer is affected by risk, represented by the variance of net returns. A similar approach was used by Dillon, Oriade, and Parsch in analyzing production risk in soybean rental arrangements in Arkansas. This approach will be employed in this study.

Users of PA are not only affected by the typical risks faced by farmers, but are also susceptible to a unique set of risk factors attributed to the technologies. While few studies are available which outline the unique risks associated with PA, it has been discussed as a tool to for risk management (Cook et al.). Lowenberg-DeBoer outlined a number of risk factors faced by PA adopters, such as the following: up-front payments for services could make the bad years worse (production risk); profitability of the technologies depends on people's ability to correctly use the technologies (human risk); obsolescence of technologies (technological risk); and investment in the technologies (financial risk) (1999). He claimed, however, that PA may also reduce risk through providing early yield estimates with remote sensing making contracting easier, and "'as-applied maps' can provide an important trace back mechanism that could reduce insurance premiums and liability claims for input suppliers, producers, and processors" (p. 278).

Another tool farmers have utilized for managing risk is the land tenure arrangement. Many studies have focused on how landowners and producers respond given certain situations. Studies have focused on how risk affects tenure arrangements (Dillon, Oriade, and Parsch; Apland, Barnes, and Justus) and how tenure arrangements affect incentives for conservation practices (Soule, Tegene, and Wiebe). General reports on producer satisfaction (Bierlen and Parsch) and on characteristics of leasing in the United States (Patterson, Hanson, and Robison) have also been

studied. Moss and Erven provided an outline for both the producer and landowner for creating "managing relationships" with each other. Studies are also available regarding the effects that technology (including PA) has on rental arrangements (Reichenberger, Lowenberg-DeBoer 2001). In particular, Reichenberger outlined five basic principles for landowners and producers to follow when making rental agreements. Two principles specifically targeted towards technology are 1) that shares should be adjusted as the technology changes, and 2) that the producer should be compensated for long-term investments.

## Model Development and Data

The previous section discussed the partial budgeting and break-even analysis procedures employed in this case study. This section will further outline the specific partial budget and break-even analysis approach in this study. After a discussion of the land tenure arrangements used for comparisons, their break-even net return equations will be identified. Concluding this section will be a description of the data used to solve these break-even net return formulas in this case study.

As required by the partial budget, only those variable expenses affected by the production/nonproduction decision are included, such as fertilizer, pesticides, seed and fuel. A different break-even net return equation was calculated for each land tenure arrangement, because of different revenue and expense combinations for the various situations. For completeness, the perspectives of both the producer and the landowner must be included when analyzing alternatives among land tenure arrangements. The land tenure arrangements to be examined are owned land, cash rent, crop share and cost share.

The distributions of revenue and expenses for the producer for each of the land tenure arrangements analyzed are shown in Table 2.1. For cash rented land, the landowner is paid a fixed annual rent for the land. If the producer does not produce on all areas of the field, it is assumed that the amount paid to the landowner would not change. Thus, the landowner's perspective on rented land will not be affected by any change in technology and will not be examined. Although a land charge will not be included in the owned land situation, a rent charge will be included in calculating net returns for the cash rent situation. However, the rent charge will not be a factor in the production/nonproduction decision because, again the amount paid to the landowner would not change.

In the final two arrangements the landowner is paid through their ownership of a percentage of the yield. For example, a one-quarter crop share arrangement will be examined where the

landowner receives one-fourth of the crop as payment and pays only for lime. The producer in the crop share arrangement receives the remainder of the crop (three-fourths) and bears responsibility for the remainder of the production expenses. A one-third cost share arrangement will also be analyzed. In this arrangement, the landowner receives one-third of the crop, but also pays one-third of the fertilizer and seed and all of the lime. The producer would receive two-thirds of the crop and pays the remainder of the production expenses.

Each break-even net return equation begins with the base, risk neutral situation as in Equation 2.3,

$$\text{Equation 2.3)} \quad BE_{NR} = \frac{VC}{P_N * Yield}$$

where $VC$ is variable costs, representing the selected costs as defined by the partial budget discussed earlier, $P_N$ is the net sales price, and $Yield$ is the yield. The net sales price was calculated as,

$$\text{Equation 2.4)} \quad P_N = P_G - Fuel - DS + LDP \text{ ,}$$

where $P_G$ is the gross sales price, $Fuel$ is the harvest and transport costs, $DS$ is drying and storage, and $LDP$ is the relevant Loan Deficiency Payment. All amounts are given in dollars per bushel. Adding the mean-variance risk component as described in Equation 2.1, a risk adjusted break-even net returns may be calculated as

$$\text{Equation 2.5)} \quad BE_{NR} = \frac{VC + \Phi \, VAR_{NR}}{P_N * Yield} \text{ .}$$

Equation 2.5 is the break-even net returns formula for the owned land situation. Break-even net returns formulas for the remainder of the land tenure arrangements are derived by modifying Equation 2.5 according to their respective split of revenues and expenses. The equation for the cash rent (producer) is,

$$\text{Equation 2.6)} \quad BE_{NR} = \frac{VC - Lime + \Phi \, VAR_{NR}}{P_N * Yield} \text{ ,}$$

for the one-quarter crop share from the landowner's perspective,

$$\text{Equation 2.7)} \quad BE_{NR} = \frac{Lime + \Phi \, VAR_{NR}}{X(P_G + LDP) * Yield} \text{ ,}$$

for the three-quarter crop share from the producer's perspective,

$$\text{Equation 2.8)} \quad BE_{NR} = \frac{VC - Lime + \Phi\, VAR_{NR}}{[(1 - X)P_N] * Yield},$$

for the one-third share cost share from the landowner's perspective,

$$\text{Equation 2.9)} \quad BE_{NR} = \frac{X(Fert + Seed) + Lime + \Phi\, VAR_{NR}}{XP_N * Yield},$$

and for the two-thirds cost share from the producer's perspective,

$$\text{Equation 2.10)} \quad BE_{NR} = \frac{VC - X(Fert + Seed) - Lime + \Phi\, VAR_{NR}}{(1 - X)P_N * Yield},$$

where $X$ represents the landowner's share of the respective arrangement (0.25 for the crop share and 0.333 for the cost share), *Lime* is the annualized expense for lime, *Fert* is the expense for fertilizer, *Seed* is the expense for seed, and $\Phi\, VAR_{NR}$ is the risk component for the individual land tenure arrangement and perspective, changing for each equation. Additionally, because landowners and producers face different risks, leading to a different standard deviation in net returns, a different RAC will be calculated for each perspective.

The solutions provide the minimum net returns needed to cover the specified costs at the expected price. Fixed costs are not included in the break-even formula calculations. When taking an area out of production, the field's total cost of production is reduced by only that portion's variable costs. Fixed costs do not change; taxes would still be owed and machinery would still be used and would continue to depreciate. Thus, since total fixed costs would not change and the total area of production has decreased, the average fixed costs associated with the remaining grids would increase. Thus, while substantial alteration of the amount of land under production might influence fixed asset ownership decisions, those influences are not included in this analysis.

These break-even equations were used to generate net returns (over specified costs) per grid, thereby creating, a net returns map. Further, by calculating a risk aversion coefficient using the McCarl and Bessler approach previously discussed, an E-V framework is used to adjust the net returns map, creating a risk-adjusted net returns map. The Z value for calculating the RAC was generated using $\alpha$ levels from 50% to 95%, in 5% increments, where 50% represented a risk neutral producer and 95% represented the highest level of risk aversion. Developing a single risk adjusted net returns map for a given producer requires specific knowledge of that producer's risk aversion

parameters. Given that producers may not know their exact level of risk aversion, four general levels of risk aversion were used to develop the risk adjusted net returns maps, low ($\alpha = 65\%$), medium ($\alpha = 75\%$), and high ($\alpha = 85\%$). Although the choice of $\alpha$ is subjective, each level is chosen based on its relative effect on net returns.

These net returns and risk adjusted net returns maps were created by collecting three years of yield monitor data from a cooperating farmer in western Kentucky and will be discussed in more detail later. Before yield monitor data can be used for analysis, it must be filtered to remove any potentially erroneous points. The initial step of this process is to adjust the yield reported by the yield monitor to the actual field yield average reported by weigh scale tickets. Although it is common to see misleading information in yield monitor data, properly calibrated equipment can minimize its occurrence. Current literature is available for proper yield monitor calibration (Shearer et al. 1999) as well as when using data from multiple combine harvesting systems (Shearer et al. 1997). The standards for speed, crop moisture and harvester throughput used to determine erroneous data points, according to expert opinion, were as follows: between twenty-five and 140 inches traveled per second; moisture between 10% and 35%; or mass flow less than seventy-five pounds per second. Any point not meeting one or more of these conditions was removed.

The yield monitor data were aggregated into 1,076 ft$^2$ grids to permit comparisons across years. Production decisions are more reliable when data are available for several years, capturing more variability in production. The problem created by the current lack of historic yield monitor data was resolved by taking average farm yields for twenty years and using the three years of yield data to predict yield maps for the missing years. An prediction procedure was developed to accomplish this. However, before implementing the prediction procedure, the historic farm yield averages were detrended to ensure consistency with this study's use of current input and output prices in calculating net returns, as well as technological developments and other factors that have a positive effect on yields. Regression analysis was used to calculate what historic yields would have been under today's conditions, as exemplified in Equation 2.11,

$$\text{Equation 2.11} \quad y = \beta_0 + \beta_1 x + \varepsilon,$$

where y is the annual yield average and x is the year. A five year yield average was calculated, as an indicator of current yield potential, and adjusted by the annual residuals found through Equation 2.11, creating the new, detrended farm level yield average for each year.

Development of the prediction procedure began with the assumption of a linear relationship between grid yield and the farm average yield within the same year, as in Equation 2.11,

$$\text{Equation 2.12} \qquad y = mx + b,$$

where $y$ is the percent of total yield for a given grid in a year to be calculated and $x$ is that year's average yield. Again, the detrended yields are used as the average yields, except for the three years of existing yield monitor data. Of the three years of yield monitor data collected, the highest and lowest averaging years were chosen to establish this linear relationship. For these two years, the spatial variability captured in the yield maps was used to calculate the percentage of average yield produced in each grid. This procedure allows spatial variability in the field to change across time, as estimated by historical farm average yields. Based on these indices, a slope and intercept ($m$ and $b$) were found between the maximum and minimum average years. The linear relationship was solved using Equation 2.12 for each grid cell.[1] Thus, the spatial variability captured in the yield maps and the temporal variability captured in historical yield averages were combined to create yield maps for seventeen years, resulting in a total of twenty years of yield maps. Finally, this prediction procedure requires there be no missing data points within the field. Therefore, a "nearest neighbor" method within Surfer® was used to estimate missing grid data within the field boundary. The "nearest neighbor" approach assigns the value of the nearest data point to each grid.

The data for this research were obtained from a large, privately owned grain farm in western Kentucky. This producer has been involved with PA since 1996, beginning with the Case AFS® system and switching to an Ag Leader® yield monitor in 1998. The following data were collected to perform this analysis: 1) yield monitor data from corn fields, 2) field level average corn yields for the yield monitored fields, 3) farm level average corn yields for twenty years (1981 - 2000), 4) estimated production expenses, 5) relevant Loan Deficiency Payments (LDP's) for the county, and 6.) the division of revenues and expenses for general land tenure arrangements.

Yield monitor data were collected from corn fields for three production years (1996, 1998, and 2000). Because of a crop rotation with soybeans, corn yield data were not available for 1997 and 1999. One 124 acre field was chosen for analysis. Descriptive statistics for those three years are presented in Table 2.2. Using the filtering process previously discussed, the remaining points produced 5,027 grid cells of 1,076 ft$^2$. Descriptive statistics for those grid cells are presented in Table 2.3, as are statistics for the twenty years of farm level average yields. Included in the table are temporal and spatial yield statistics for the estimated yield monitor data. All statistics are expressed on a per acre basis.

Production expenses used in the analysis were based on the 1998 Yellow Corn Enterprise Study from the Kentucky Farm Business Management Program. Because a    partial budget approach was used in the analysis, only those production costs that would change were included. The total reduced costs from moving out of production were $171.62 per acre, including interest on variable operating expenses at an annual rate of 9% for six months, or $4.24 per grid cell. Not included in this total were the yield related expenses, drying, storage and fuel, which were included in the net sales price. The total fuel expense reported by KFBM included more than just the harvest and transport cost for the crop which would be the only fuel expenses required in the partial budget. However, because the reported expense was a modest amount ($6.74 per acre, or $0.04 per bushel), it was not an unreasonable assumption to include the entire amount as yield dependant with the net sales price.. The annualized cost for lime was $6.25 per acre, or $0.15 per grid. The output price for corn, $2.35 per bushel, came from University of Kentucky enterprise budgets, updated in 2001. The net sales price, as outlined by Equation 2.4 was $2.588 per bushel. The $0.33 per bushel LDP was the average LDP producers in the area of the study received, as reported by the Farm Service Agency.

## Results

Results from this study are presented for both yield estimates as well as economic findings. Economic results include net returns descriptive statistics and proportion of the field to remain in production.

Descriptive statistics for yields are provided in Tables 2.2 and 2.3. The annual mean, maximum, minimum, standard deviation, and coefficient of variation of yields in Table 2.2 are based on the spatial yield monitor data of one field collected in 1996, 1998, and 2000. These statistics provide insight regarding the spatial variation within the field used for analysis. One should note that the most spatially variable year was the year with neither the highest, nor lowest field average yield. Additionally, the highest and lowest yielding years displayed similar spatial variation.

In Table 2.3, the first two data columns are the same statistics for the farm level yield averages from the years 1981 through 2000, for both the actual yields and the detrended yields, a process explained in the previous section. These statistics give information on the temporal variation for the entire farm. As explained earlier, the yield monitor data and the farm averages were used to create spatial yield data for the entire twenty year period. Those statistics are found in the last two data columns of Table 2.3. The temporal yield statistics column is based on the annual field

level yield averages of the entire twenty year period, while the spatial yield statistics are based on the yield averages per grid for twenty years, both expressed on a per acre basis. Data were not recreated for the three years in which actual yield monitor data was available. One should note that in two out of the three recent years, the field used in this case study had average yields higher than the twenty year farm level average, as expected given general trends of increasing farm productivity. Additionally, temporal and spatial variation are very similar.

One of the primary objectives of this study was to examine how risk aversion levels would affect the amount of land in production for different land tenure arrangements. These results are found in Table 2.4. This table reports the percentage of grids within the field which cover the selected costs, for each land tenure arrangement examined and for four risk aversion levels, neutral, low, medium and high. As one would expect given the inherent risk in agricultural production, the more risk averse an individual becomes, the lower percentage of the field they would keep production.

On the producer's side, when ranking the amount of land to remain in production from highest to lowest, this order is consistent in the neutral and low risk aversion levels. This order changes at the medium and high risk aversion levels, as cost share moves from third to first in terms of keeping the most land in production. One explanation for this result is that producers choose a cost share arrangement as a risk management tool. As the level of risk increases, so does the impact of this arrangement for risk management. For the landowner, the crop share arrangement consistently keeps the most land in production. Comparing the landowner and producer under the same arrangement, the landowner keeps more land in production, with the exception of the high risk averse cost share arrangement.

Intuitively, it makes sense that the landowner in a crop share arrangement would not remove any part of the field from production. This person pays a relatively small part of the expenses ($6.25 per acre, or $0.15 per grid for lime on an annualized basis) and is receiving one-quarter of the crop as payment. Although this individual would have the higher percentage of the field in production regardless of risk aversion preference, it is not consistently 100%. In fact, the high risk averse landowner would leave over 7% of the field out of production. Again, this shows the effect that high levels of risk aversion have on net returns. Some grids are not productive enough to cover even small expenses for a landowner under this crop share arrangement.

Descriptive statistics of net returns under full production are shown in Tables 2.5 and 2.6, as are statistics if the individual implemented the nonproduction decision strategy. The mean and

coefficient of variation results for the producer's net returns under the production situation, as well as for the nonproduction situation for the various risk aversion levels are displayed in Table 2.5. Again, it should be noted that while rent was charged to the producer in the cash rent situation in the calculation of net returns, it was not considered in the production/nonproduction decision because it will be paid regardless. Initially, cash rent enjoys the highest mean net returns of the three rental situations, and the cost share shows the lowest mean net returns. Under a highly risk averse situation, this trend reverses. While all producers experienced an increase in net returns as production becomes more selective, the biggest gain in net returns was the crop share situation, followed by cost share. This outcome is expected because the landowners are paid according to production, not according to how much land is being farmed.

For the producer, adopting a different land tenure arrangement has more of an effect on risk than the risk attitude of the decision maker. The owned land situation experiences the lowest level of risk among all producers. Of the non-land owning producers, the cost share arrangement bears the least risk. Again, this is consistent with expectations because cost share producers share more of the production expenses with the landowner as    compared to the cash rent and crop share producers. Each situation exhibits a fairly substantial risk reduction initially under selective production while producing a relatively low reduction in expected net returns. The crop share arrangement shows the largest risk reduction, as the coefficient of variation (CV) changes from 42.1% under full to production, to 40.2% for a risk neutral producer and to 31.6% for a highly risk averse producer. The cash rent situation exhibits the smallest risk reduction. The CV actually increased in the cash rent situation when moving from medium to high risk aversion. This is caused by a substantial drop in mean net returns, despite a decrease in the standard deviation.

Results for the landowners, provided in Table 2.6, are less interesting. First, there is no change between production and nonproduction for the risk neutral individual. The crop share arrangement maintains a greater mean net returns and lower CV for each risk aversion level. There is only a slight potential for risk reduction for the landowners (slightly more for the cost share than the crop share arrangement). However, the mean net returns for the cost share owner decline more than those of the crop share. As illustrated in Table 2.4, the crop share owner keeps substantially more land in production than the cost share owner. In figuring the net returns per acre for the risk averse situation, the cost share owner receives more ($90.40) than the crop share owner ($88.51).

Figures 1 and 2 are the risk adjusted net returns maps for the owned land and cost share land tenure arrangements, respectively, for the produce/no produce decision. The green areas are those

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areas where production would take place regardless of risk aversion level. At any risk aversion level, production is not economically justified in the red areas. A low risk averse producer would not produce in the yellow or red areas, a medium risk averse producer would not produce in the black, yellow, or red areas, and a high risk averse produce would not produce in the blue, black, yellow, or red areas. Table 2.3 can be reviewed for the percentage of field to remain in production for these producers, as well as the other land tenure arrangements.

**Conclusions**

The nature of precision technologies is that a large amount of data will be collected. This data has altered the type of analysis from which producers can base decisions, making decision making more complex. Before PA, producers made decisions based on field level data through tools such as simple, field-based enterprise budgets, which can be completed with pen and paper or simple spreadsheet. By collecting information at the sub-field level, a greater amount of detailed information can be gathered from each field. The decision maker must now be able to manage and analyze this data for making decisions. This more complex data has led to the need for more detailed decision tools with the capability of handling this type of data. Few decision tools are currently available for users of PA. This research is the beginning of a new era of decision aids for PA users. Specifically, by combining the site specific yields from yield monitor data with expenses from the same location, areas of a field that do not cover expenses can be identified and removed from production to increase farm profitability. The effects of risk and land tenure arrangements can be included in the analysis to determine their effects on the production/nonproduction decision.

Before yield monitor data can be used in making decisions, users must filter the data to remove the erroneous points. Although some error in yield monitor data is inevitable, as the development of decision aids continues and producers have new options of data analysis, standards for yield monitor collection can be developed. As users become more proficient with yield monitor data and see the benefits from using such data, they may become more proficient in data collection methods, making analysis easier, more consistent and reliable.

Additional notes on the decision to move areas of fields out of production deserve to be mentioned. In the results section, it was assumed that the individual would remove all eligible land from production. This may not always be the case. Standards must be developed to help producers find the appropriate size and placement of the unprofitable areas to further justify removing them from production. When is it advantageous for producers to not produce on an interior part of a

field?  Should the area equal an acre, half an acre, or even a quarter of an acre?  Producers will have to make these decisions until minimal fallow area is determined by further research.

This study was not without areas of concern.  One issue is the precision of the prediction procedure used to develop seventeen out of the twenty years of yield maps.  Although the main objective of this research was the production/nonproduction decision and not how to make historical yield maps, results are a direct reflection of the prediction procedure's precision.  Furthermore, according to Table 2.3, there are no situations in which the producer and landowner completely agree on the areas for production.  It would be up to the parties involved to resolve the issue in a mutually beneficial decision.

Finally, it is highly unlikely that a producer would remove land from production and do nothing with it.  In the break-even net return equations, no costs were included for establishment and maintenance costs of the land.  Producers wishing to remove land from production would need to analyze options available to them.  One option for eligible land, is enrollment into the Conservation Reserve Program (CRP).  This would provide the landowner additional revenue for land removed from production.  Options such as these were not included in this study because of their long term commitments of the land.  Only the corn enterprise was examined here, while land is enrolled in the CRP for many years.  If producers wish to consider this alternative, they must also consider the effects of profitability to all enterprises involved in crop rotation for a given area.

The objective for developing decision aids is to make them available to those who can use them.  The next step in the process is the development of a vehicle to make this a reality.   One possibility is a web-based economic advisory service to which producers can send the relevant data, such as yield maps and cost structures, and the service would return results back to the producer.  The information and skills developed through this case study can be used to create a pilot project.  This pilot project will help address the issues involved for opening this service to users of PA.

Table 2.1.  Distribution of revenue and expenses according to land tenure arrangement.

| Land Tenure Arrangement | Revenue | Expenses |
|---|---|---|
| Owned Land | 100% Yield + LDP | 100% |
| Cash Rent, Producer | 100% Yield + LDP | 100% - Lime + Cash Rent |
| Crop Share, Landowner | 25% Yield + LDP | Lime |
| Crop Share, Producer | 75% Yield + LDP | 100% - Lime |
| Cost Share, Landowner | 33% Yield + LDP | Lime + 33% (Fertilizer + Seed) |
| Cost Share, Producer | 67% Yield + LDP | 100% - 33% (Fertilizer + Seed)- Lime |

Table 2.2.  Descriptive spatial statistics from yield monitor data across grids for years available (bushels per acre).

| Year | Mean | Maximum | Minimum | Standard Deviation | Coefficient of Variation |
|---|---|---|---|---|---|
| 1996 | 190.7 | 348.2 | 17.4 | 35.2 | 18.5% |
| 1998 | 132.6 | 223.1 | 27.5 | 24.2 | 18.3% |
| 2000 | 181.0 | 301.4 | 11.0 | 44.5 | 24.6% |

Table 2.3.  Descriptive statistics of farm level average yields and estimated yield monitor data from 1981-2000 (bushels per acre).

| Statistics | Farm Level Average Yields[1] | | Estimated Yield Monitor Data | |
|---|---|---|---|---|
| | Actual | Detrended | Temporal[2] | Spatial[3] |
| Mean | 128.5 | 134.38 | 139.9 | 139.9 |
| Maximum | 168.0 | 171.52 | 190.7 | 221.6 |
| Minimum | 79.0 | 96.64 | 97.0 | 34.2 |
| Standard Deviation | 19.3 | 16.82 | 22.6 | 23.1 |
| Coefficient of Variation | 15.0% | 12.5% | 16.2% | 16.5% |

[1.] Farm level average yields are temporal averages, based on the twenty years of historical yields.
[2.] Temporal yield data are based on the annual field averages for 20 years.
[3.] Spatial yield data are based on yield averages per grid for 20 years.

Table 2.4.  Percentage of field to remain in production.

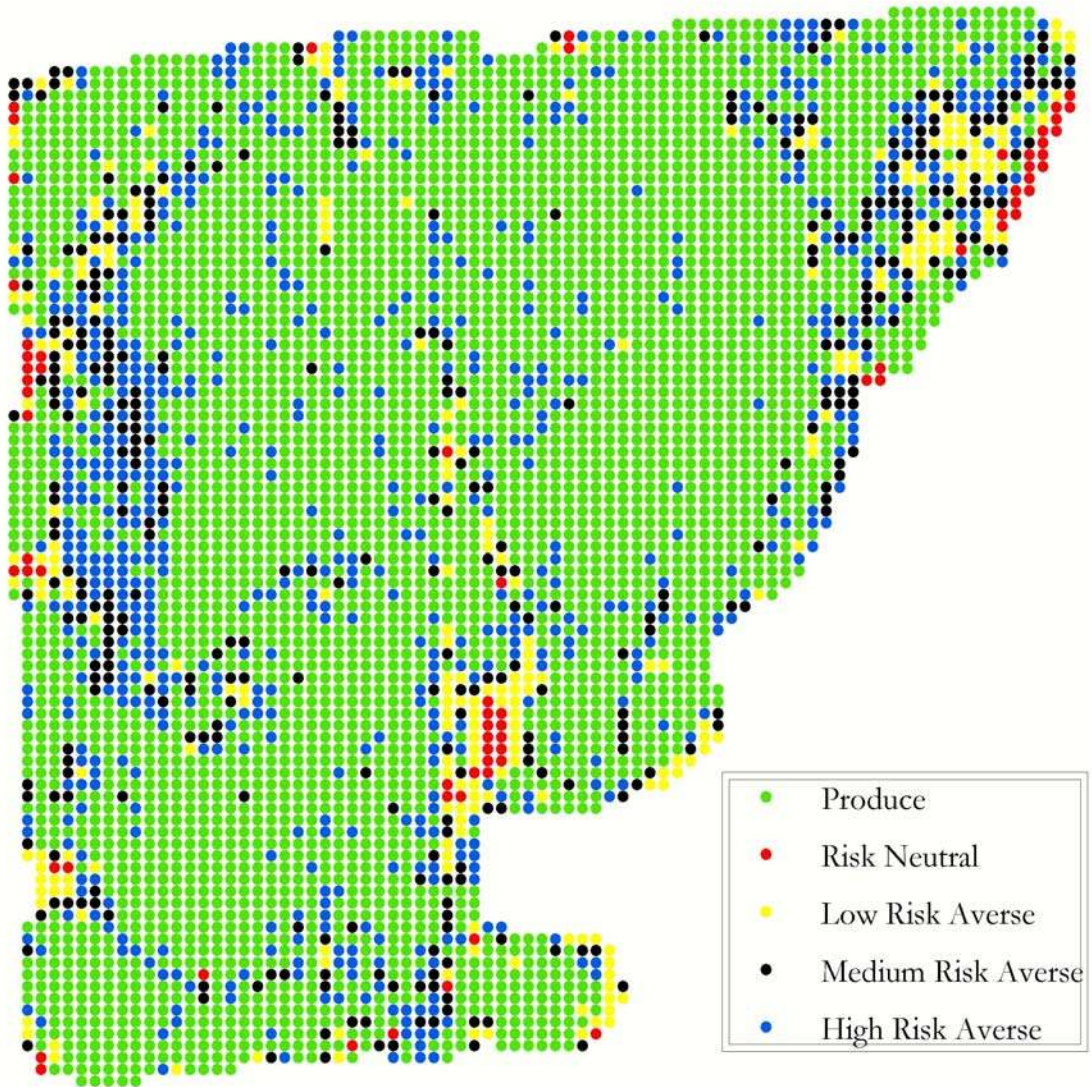| | Levels of Risk Aversion | | | |
|---|---|---|---|---|
| **Producer:** | Neutral | Low (65%) | Medium (75%) | High (85%) |
| Owned Land | 98.61% | 93.48% | 85.93% | 72.00% |
| Cash Rent | 98.73% | 93.87% | 86.35% | 72.65% |
| Crop Share | 96.36% | 89.46% | 82.49% | 69.54% |
| Cost Share | 97.35% | 92.68% | 87.17% | 77.82% |
| **Landowner:** | | | | |
| Crop Share | 100.00% | 99.24% | 97.49% | 92.92% |
| Cost Share | 99.96% | 96.52% | 89.28% | 74.64% |

Table 2.5. Descriptive temporal statistics of the producer's net returns for different land tenure arrangements, risk aversion levels and the production/nonproduction decision.

| Land Tenure Arrangement | Statistics | Full Production | Risk Aversion Levels for Non Production | | | |
|---|---|---|---|---|---|---|
| | | | Neutral | Low | Medium | High |
| Owned Land | Mean | $23,669 | $23,716 | $23,237 | $22,004 | $18,943 |
| | CV | 30.8% | 30.3% | 28.4% | 26.6% | 24.4% |
| Cash Rent | Mean | $14,081 | $14,120 | $13,649 | $12,428 | $9,376 |
| | CV | 51.8% | 51.0% | 48.6% | 47.4% | 49.8% |
| Crop Share | Mean | $13,003 | $13,146 | $12,844 | $12,250 | $10,658 |
| | CV | 42.1% | 40.2% | 36.8% | 34.5% | 31.6% |
| Cost Share | Mean | $12,848 | $12,934 | $12,769 | $12,357 | $11,371 |
| | CV | 37.9% | 36.7% | 34.5% | 32.6% | 30.3% |

Table 2.6. Descriptive statistics of the landowner's net returns for different land tenure arrangements, risk aversion levels and the production/nonproduction decision.

| Land Tenure Arrangement | Statistics | Full Production | Risk Aversion Levels for Non Production | | | |
|---|---|---|---|---|---|---|
| | | | Neutral | Low | Medium | High |
| Crop Share | Mean | $10,764 | $10,764 | $10,725 | $10,597 | $10,216 |
| | CV | 17.6% | 17.6% | 17.3% | 16.9% | 16.2% |
| Cost Share | Mean | $10,521 | $10,521 | $10,354 | $9,797 | $8,382 |
| | CV | 23.1% | 23.1% | 22.0% | 20.6% | 18.9% |

Figure 2.1: E-V Map of 20 year average, decision not to produce for owned land.



Notes: Green area would always remain in production. At any risk aversion level, production is not economically justified in the red areas. A low risk averse producer would not produce in the yellow or red areas, a medium risk averse producer would not produce in the black, yellow, or red areas, and a high risk averse produce would not produce in the blue, black, yellow, or red areas.

Figure 2.2: E-V Map of 20 year average, decision not to produce for cost share land, producer's perspective.
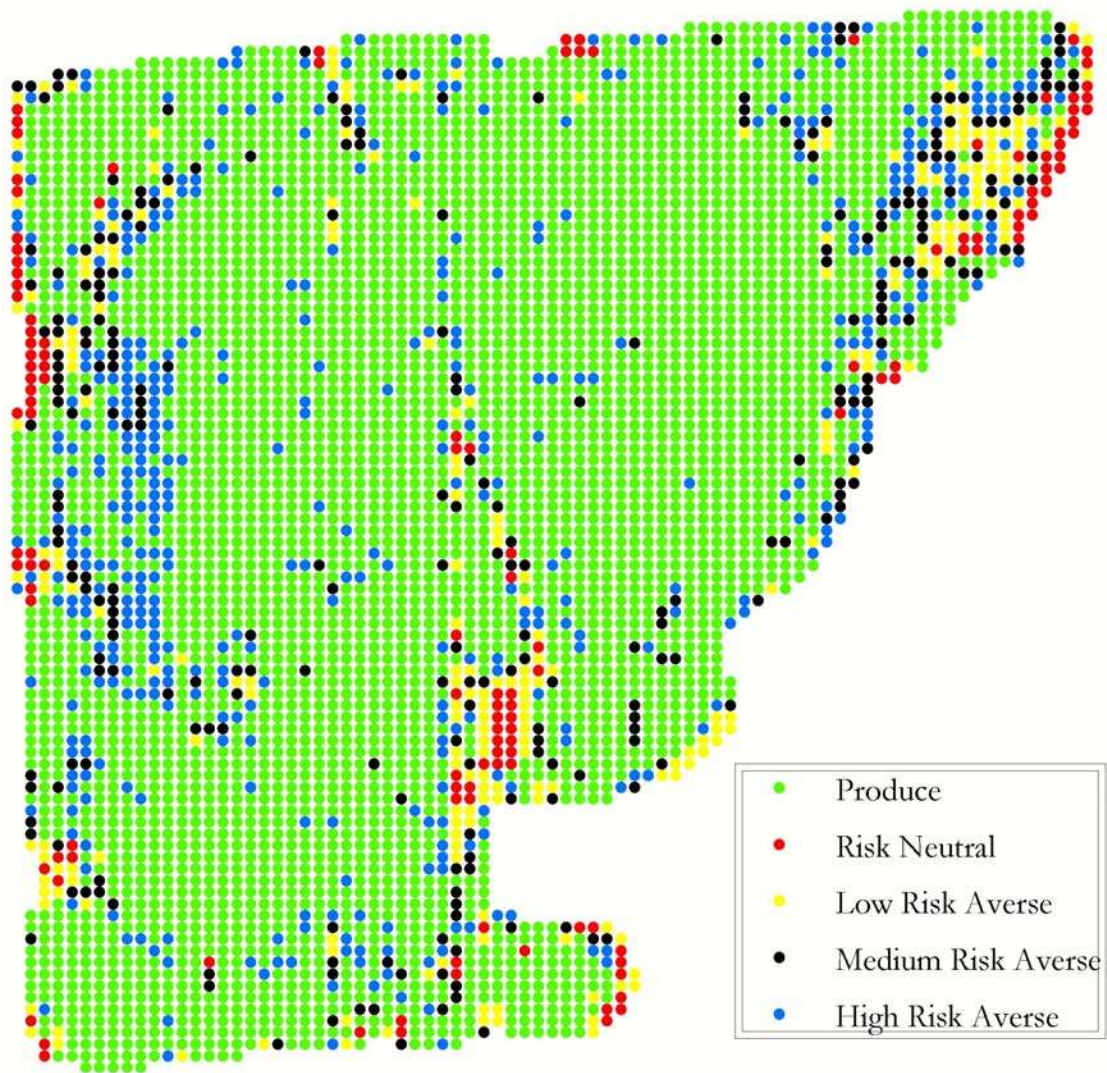


Notes: Green area would always remain in production. At any risk aversion level, production is not economically justified in the red areas. A low risk averse producer would not produce in the yellow or red areas, a medium risk averse producer would not produce in the black, yellow, or red areas, and a high risk averse produce would not produce in the blue, black, yellow, or red areas.

**Endnotes**

1.  The prediction procedure was established based on the following linear relationship,

$$Yld_{t,g} = \beta_{0,g} + \beta_{1,g} Yld_{Fmavg,t},$$

where $Yld_{t,g}$ = the farm average yield in time period, t, for grid, g, and

$$\beta_{1,g} = \frac{Index_{1,g} - Index_{0,g}}{Yld_{1,fdavg} - Yld_{0,fdavg}},$$

where $Yld_{Fdavg}$ = the field average yield in time period, t per grid, g, and

$$\beta_{0,g} = Index_{1,g} - \beta_{1,g} * Yld_{1,Fdavg}.$$

The index per grid is calculated by,

$$Index_{i,g} = \frac{Yld_{i,g}}{Yld_{i,Fdavg}} * 100$$

where, i=0 for minimum Fdavg and i=1 for maximum Fdavg.

# Chapter Three

## Risk Management Tools in Precision Agriculture

### Introduction

One of the primary responsibilities of the farm manager is making decisions. These decisions are based on the goals and mission of the farm business, which are typically based on profit maximization (Boehlje and Eidman). While many factors influencing this goal can be controlled by the farm manager, such as economically efficient input use, other factors cannot. These uncontrollable events, such as weather, market fluctuations, and government intervention, introduce a great deal of uncertainty into the farm business. This uncertainty makes the inclusion of risk in the decision-making process a necessity for producers to reach their goal of profit maximization.

Producers must be able to measure risk to include it in the decision-making process. Risk management and statistics textbooks contain a variety of measures for risk analysis. Statistics such as variance and standard deviations are popular methods of measuring risk. While these statistics are useful in gaining information within one data set, one single statistic would not often be an accurate reflection of riskiness when comparing sets of distributions.

Identifying key statistics is the first step in generating an accurate picture of the production risk within a field. This study will examine three methods for identifying and mapping risk in a precision agriculture setting by creating a break-even probability, a coefficient of variation (CV), and a mean-variance (E-V) map. Break-even probabilities calculate the percent chance that break-even production levels, the minimum yield required for net returns over specified costs to equal zero, will occur, based on historic production levels. Thus, the higher the break-even probability, the lower the risk. The CV reports the degree to which a distribution varies (Tashman and Lamborn). The larger the CV, the greater the variability, thus the more "risky". Finally, an E-V framework can be used to adjust net returns according to defined levels of risk aversion, such as neutral, low, medium and high. The producer can compare the results among these risk measures to gain information on the level of risk faced in agricultural production.

Calculating these measures and making decisions depends on the ability to gather accurate farm information. The development of precision agriculture (PA) technologies allows producers to collect and analyze information on a spatial basis. This information can then be used to aid producers in their ability to make decisions on a spatial basis, such as calculating the various levels of risk across a field.

The role of PA in the decision-making process will be the focus of this study.  As the literature will show in the next section, few decision aids have been developed to help PA practitioners make decisions from the data they have collected.  The overall purpose of this study is to develop economic decision aids for users of PA in the area of risk management.  Specifically, this objective will be achieved through the following procedures: 1) identify key statistics for measuring risk which will reflect changes in temporal risk, 2) develop procedures using Geographical Information Systems (GIS) software and yield monitor data to visually identify this temporal risk spatially throughout a field, and 3) provide an empirical application and interpretation of the resulting risk maps using crop insurance as an example.

This study will add to the current literature in several ways. First, it will add to the limited literature available in using PA data for decision making.  Secondly, it will demonstrate PA's use as a decision-making tool specifically for risk management.  While a small number of studies have professed PA's usefulness in risk management, they have not demonstrated how site-specific data can be used in decision making.  Finally, it will offer some considerations in the potential of using PA data for decisions.

## Theoretical Framework

The first step in developing risk management tools using PA data is outlining the underlining risk theory.  This section will begin that discussion, including E-V, break-even analysis and the CV. Following the risk framework will be a presentation of the current literature regarding the role PA has played in risk management.

The U. S. Department of Agriculture (USDA) defines risk as "uncertainty that affects an individual's welfare, and is often associated with adversity and loss" (Harwood et al.). The Risk Management Agency (RMA) of the USDA adds that risk has two elements: a level of being "bad" and chance.  For an activity to be risky, there must be a chance that something bad will happen.  In agriculture, farmers constantly deal with situations in which there is a chance that something "bad" may happen.

The USDA has outlined five types of risk in agriculture (Harwood et al.).  *Production or yield risk* is particularly unique to agriculture because of its susceptibility to the weather.  Many events that affect production, such as drought, flooding, or disease, are caused by unfavorable weather conditions.  *Price or market risk*, although not as unique to agriculture as production risk, refers to the risks producers face from changes in input and output prices, particularly after the production

process has begun. *Institutional and social risk* relates to how changes in governmental policies and regulations affect agriculture. It is because of *human or personal risk* that agriculture remains one of the most hazardous occupations[1]. Human risk can range from injury on the job to risks faced because of "opportunistic behavior and the reliability of contracting partners" (p. 7). Finally, agricultural producers face *financial risks* resulting from their susceptibility from fluctuating interest rates to liquidity and solvency problems, often as a result of influences from other risks. While all areas of risk affect decision making, production risk will be main focus of this study.

The evolution of risk in the role of decision making began with the pioneering game theory work of Von Neumann and Morgenstern. It was their seminal work which dictated that the decision maker uses expected utility to make their "best" choice (Day). In making decisions, one must chose among a set of alternatives with varying degrees of risk and a set of probability distributions. Their decision is based on finding the alternative which maximizes their expected utility (Freund).

The next step in the evolution of risk theory stated that decisions could be based on only two key statistics, the mean and variance of the models (Varian; Boisvert and McCarl). Markowitz began the development of E-V analysis, looking at investment strategies (Varian, Young). The E-V model states that decisions are made through the mean and variance of net returns, preferring a higher mean and lower variance. It has been found that E-V analysis is a proper tool to use, as being consistent with expected utility modeling, when the stochastic variables differ only by location and scale (Meyer) such as when returns are normally distributed (Boisvert and McCarl). The framework for E-V analysis is as follows:

$$\text{Equation 3.1.) Max: } EV = \sum \bar{r_i} * x_i - \Phi * Var_y$$

where EV is the risk adjusted net returns, $\bar{r_i}$ is the average rate of return, $x_i$ is the dollar amount invested, $\Phi$ is the risk aversion parameter, and $Var_y$ represents the variance of net returns.

Difficulty in using this approach arises because the risk aversion coefficient (RAC) must be known. McCarl and Bessler developed an approach to calculate a level of risk aversion when the utility function is not known. Their formula for calculating RACs is as follows:

$$\text{Equation 3.2.) } \Phi = \frac{2Z\alpha}{S_y},$$

where $\Phi$ is the risk-aversion coefficient, $Z_a$ is the standardized normal Z value of $\alpha$ level of significance and $S_y$ is the relevant standard deviation. The resulting RAC, when applied to equation

3.2, gives the level at the which the producer is affected by risk, represented by the variance of net returns. A similar approach was used by Dillon, Oriade, and Parsch in analyzing production risk in soybean rental arrangements in Arkansas. This approach will again be employed in this study.

Other, more simplified, methods are available for measuring risk, and farm management texts (e.g. Kay and Edwards) discuss a variety of statistics for measuring risk. The literature confirms the use of statistics such as the CV and break-even analysis as means for measuring risk. The CV has been identified in several studies as a method for measuring risk. Topics include the sustainability of agricultural cropping systems (Lu, Watkins, Teasdale), using soybean oil in horticultural crops (Pendergrass et al.), and risk sensitivity analysis of honeybees (Shafir et al.). These studies have all demonstrated that the higher the CV, the more risky the situation.

Break-even analysis literature equally demonstrates its usefulness as a farm management tool. The foundation for break-even analysis is presented in many basic farm management textbooks (e.g. Kay and Edwards). The most basic form of break-even analysis calculates either the yield or commodity price to be received, given selected costs, to generate a return above those selected costs of zero dollars. Examples include the calculation of the maximum level of an input price (diesel fuel) one would pay to break even (Dillon and Roberts), calculation of break-even points among enterprises (Dillon 1992), break-even planting and harvesting decisions (Dillon 1994), and the elasticity of break-even prices between enterprises (Dillon and Casey). Other studies have demonstrated break-even analysis as a decision rule (Pearce et al., Roberts, Pendergrass and Hayes). Roberts, Pendergrass and Hayes demonstrated the use of break-even analysis as a decision criteria in studying the economics of Roundup Ready® (RR) soybeans. They concluded that if the producer expected to receive a conventional yield less than the break-even yield found with RR soybeans, the producer should switch to RR soybeans.

While break-even analysis can be used to measure risk, farmers also want tools to help manage risk. One such option available to farmers is crop insurance. Current yield-based insurance, commonly referred to as actual production history, or APH, available to farmers include the Multiple Peril Crop Insurance (MPCI), Group Risk Plan (GRP) and Dollar Plan, as well as several pilot programs across the States (RMA online). As of July 22, 2002, there were more than 866,000 insured acres in Kentucky under such programs (RMA online). The lack of precise yield data has been identified as one of the most limiting factors in predicting accurate insurance premiums (Goodwin and Ker; Ker and Goodwin). With the introduction of PA technologies, more accurate ways of making such measurements have been established.

Literature regarding PA is quite diverse. However, a majority of the studies are focused on agricultural production and profitability. Studies are available ranging from adoption of the technologies (Shearer et al. 1999; Swinton, Harsh, and Ahmad; English et al.), to variable rate technologies (Engebretson; Clark and McGuckin) to profitability (Engebretson; Swinton and Lowenberg-DeBoer; Schnitkey, Hopkins, and Tweeten). The most comprehensive review of PA profitability studies came in 2000, by Lambert and Lowenberg-DeBoer. Of the 108 studies they collected reporting economic results, 63% reported positive economic benefits, 26% reported mixed results, and 11% reported no economic benefits.

Users of PA are not only affected by the typical risks faced by farmers, but must also deal with a unique set of risk factors because of the technologies. Lowenberg-DeBoer (1999b) outlined a number of risk factors faced by PA adopters, such as the following: up-front payments for services could make the bad years worse (production risk); profitability of the technologies depends on people's ability to correctly use the technologies (human risk); obsolescence of technologies (technological risk); and investment in the technologies (financial risk). In addition, he claimed that PA may also reduce risk through providing early yield estimates with remote sensing, make contracting easier, and "'as-applied maps' can provide an important trace back mechanism that could reduce insurance premiums and liability claims for input suppliers, producers, and processors" (p. 278).

However, the role of PA in the area of decision making has been more limited. While there has been general discussion on decision making and information needs in PA (Watermeier; Atherton et al., Fleming et al.), the need for decision-making tools has been identified as a weakness in the literature (Gibbons; Atherton et al.; Lowenberg-DeBoer 1996). Lowenberg-DeBoer (1996) claims that the lack of decision support has been a factor in low adoption rates of PA. Adding to the general break-even studies listed above, break-even analysis has recently begun to appear in PA literature. Studies include spatial break-even analysis for VRT (English, Roberts and Mahajanashetti), ownership of precision equipment (Gandonou et al.) and enrolling buffer strips into the Conservation Reserve Program (CRP) (Stull et al.).

Using yield maps for decision making has been introduced in the literature, but the number of studies is very limited. In 1997, Larscheid, Blackmore and Moore outlined four models for using yield maps to make management decisions, two yield maps and two 'money maps'. Each type of map was completed, one with one year's data and the other with more than one year's data. The yield map with only one year's data was suggested to be only a starting point for decisions such as

implementing variable rate technology. The single year 'money map' simply added output prices and expenses to the single year yield map. They conceded that the single year models were intended for short run decisions only, while their multiple year models were for long term decision making. The multiple year yield map displayed information on the temporal and spatial trends in yields. For the final map, the multiple year yield map was adjusted with economic variables to compute their version of a 'profit map'.

Precision agriculture's usefulness as a risk management tool extends beyond its capabilities to record accurate yields for crop insurance. Any statistic can be calculated for individual grids within a field using yield monitor data. The field can then be mapped according to these particular statistics. This section has discussed the use of an E-V framework, the CV and break-even analysis as risk management tools. The next section will outline the procedures for developing risk maps from yield monitor data using these statistics.

## Model Development and Data

Risk maps were created by collecting three years of yield monitor data from a cooperating producer in western Kentucky. This data will be discussed in greater detail later. Before yield monitor data can be used for analysis, it must be filtered to remove any erroneous points. Yields reported by the yield monitor were first adjusted to actual yield averages reported by weigh scale tickets. Standards for speed, crop moisture and harvester throughput used to determine erroneous data points, according to expert opinion, were as follows: between twenty-five and 140 inches traveled per second; moisture between 10% and 35%; or mass flow less than seventy-five pounds per second. Any point not meeting all three conditions was removed. Although it is common to see misleading information in yield monitor data, properly calibrated equipment can minimize its occurrence. Current literature is available for proper yield monitor calibration (Shearer et al. 1999) as well as when using data from multiple combine harvesting systems (Shearer et al. 1997).

The yield monitor data were averaged into 1,076 ft$^2$ grids to permit comparisons across years. Production decisions are more reliable when data are available for several years to capture more variability in production. The problem created by the current lack of historic yield monitor data was resolved by taking average farm yields for twenty years and using the three years of spatial yield data to estimate yield maps for the unavailable years. A yield prediction procedure was developed to accomplish this. However, before implementing the prediction procedure, the historic farm yield averages were detrended to ensure consistency with this study's use of current input and

output prices in calculating net returns, as well as technological developments and other factors that have a positive effect on yields. The data were detrended according to the process used in many crop insurance programs, as well as that suggested in Gallager and Goodwin and Ker, assuming yields follow a linear trend. Equation 3.3 was used for regressing yields,

$$\text{Equation 3.3} \quad y = \beta_0 + \beta_1 x + \varepsilon,$$

where $y$ is the annual yield average and $x$ is the year. Each year's adjusted yield, $\text{Yield}_y$ was then calculated using Equation 3.4,

$$\text{Equation 3.4} \quad Yield_y = \frac{\text{Actual Yield in Year x}}{\text{Trend Yield in Year x}} * \text{Trend Yield for 2000}$$

Development of the prediction procedure began with the assumption of a linear relationship between yield per grid and the farm average yield within the same year, as in Equation 3.5,

$$\text{Equation 3.5} \quad y_g = m_g x + b_g$$

where $y_g$ is the percent of total yield for a given grid, $g$ in a year to be calculated and $x$ is that year's average yield. Again, the detrended yields were used in this prediction procedure, except for the three years of existing yield monitor data which was not replicated. The highest and lowest averaging years were chosen among the three years of yield monitor data collected to establish this linear relationship. For these two years, the spatial variability captured in the yield maps was used to calculate the percentage of average yield produced in each grid. This procedure allowed spatial variability in the field to change across time, as estimated by historical farm average yields. Based on these indices, a slope and intercept ($m$ and $b$) were found between the maximum and minimum average years. The linear relationship was completed by solving Equation 3.4 for each grid cell[2]. Thus, the spatial variability captured in the yield maps and the temporal variability captured in historical yield averages were combined to create yield maps for seventeen years, resulting in a total of twenty years of yield maps. Finally, this prediction procedure required there be no missing data points within the field. Therefore, a "nearest neighbor" method within Surfer® was used to estimate missing grid data within the field boundary. The "nearest neighbor" approach assigned the value of the nearest data point to each grid.

Data for this research were obtained from a large, privately owned grain farm in western Kentucky. This producer's involvement with PA began in 1996 with the Case AFS® system, switching to an Ag Leader® yield monitor in 1998. The following data were collected to perform

this analysis: 1) yield monitor data from corn fields, 2) field level average corn yields for the yield monitored fields, 3) farm level average corn yields for twenty years (1981 - 2000), 4) estimated production expenses, 5) relevant Loan Deficiency Payments (LDPs) for the county, and 6) crop insurance producer paid premiums, indemnity payments, and insurance trigger yield levels.

Yield monitor data were collected from corn fields for three production years (1996, 1998, and 2000). One thirty-nine acre field was chosen for analysis. The yield monitor collected data at one, two and three second intervals. Descriptive statistics for those three years are presented in Table 3.1. Using the filtering process previously discussed, the remaining points produced 1,588 grids of 1,076 ft$^2$. Descriptive statistics for those grids are presented in Table 3.2, as are statistics for the twenty years of farm level average yields. Included in the table are both temporal and spatial yield statistics for the estimated yield monitored data. All statistics are expressed on a per acre basis.

The series of risk maps begins with a twenty year average net returns map. Net returns per grid were calculated according to Equation 3.6:

$$\text{Equation 3.6} \quad NR_g = \frac{\sum (Yield_g * P_N) - TVC}{n},$$

where $Yield_g$ is the yield per grid g, $P_N$ is the net sales price, $TVC$ are the total variable costs, and $n$ is the number of years in the study. The net sales price was calculated as follows:

$$\text{Equation 3.7} \quad P_N = P_G - Fuel - DS + LDP,$$

where $P_G$ is the gross sales price, $Fuel$ is the harvest and transport costs, $DS$ is drying and storage, and $LDP$ is the relevant Loan Deficiency Payment. All amounts are given in dollars per bushel.

The remainder of the maps are based on these average net returns per grid. The break-even probabilities map calculates the percent chance that an individual grid will break-even, based on its twenty year average of net returns. The CV map reflects the CV of average net returns for each grid over the twenty year history.

Finally, the E-V risk map of net returns is based on the break-even point of net returns based Equation 3.1. Those break-even points are outlined in Equation 3.8:

$$\text{Equation 3.8} \quad BE_{NR} = \frac{VC + \Phi \, VAR_{NR}}{P_N * Yield},$$

where $\Phi VAR_{NR}$ is the risk component of net returns. The Z value for calculating the RAC was generated using $\alpha$ levels from 50% to 95%, in 5% increments, where 50% represented a risk neutral producer and 95% represented the highest level of risk aversion. Given that producers would likely

not know their exact risk aversion level, four general levels of risk aversion were used to develop the E-V net returns maps, low ($\alpha$ =60%), medium ($\alpha$ =70%), and high ($\alpha$ =80%).  Although the choice of $\alpha$ is subjective, each level was chosen based on its relative effect on net returns.

Production expenses used in the analysis were based on the most recent data available.  The production expenses used in the study came from the 1998 Yellow Corn Enterprise Study from the Kentucky Farm Business Management (KFBM) Program.  Total variable costs (TVC) were $178.84 per acre, or $4.42 per grid.   This does not include the yield related expenses, drying, storage and fuel, which were included in the net sales price.   The total fuel expense reported by KFBM included more than harvest and transport costs, which are the only fuel expenses required by the partial budget.  However, because the reported expense was a modest amount ($6.74 per acre, or $0.04 per bushel), it was not an unreasonable assumption to include the entire amount as yield dependent with the net sales price.  The output price for corn, $2.35 per bushel, came from University of Kentucky enterprise budgets, updated in 2001.  The net sales price, as outlined by Equation 3.4 was $2.588 per bushel.  The LDP payment of $0.33 per bushel was the average LDP payment producers in the area of the case study received, as reported by the Farm Service Agency.  Total fixed costs (TFC), as reported by KFBM, were obtained to identify grids whose net returns cover all costs in the net returns map.  Fixed costs were again taken from KFBM, with the exception of machinery interest, which was not available from KFBM.  This expense was found in the 2002 University of Tennessee No-till Corn Field Crop Budget.  TFC were $36.79 per acre, or $.91 per grid.

As previously discussed, an insurance option was added to create a second series of risk maps, to observe how this risk management tool would affect risk statistics of net returns.  An Actual Production History (APH) plan was chosen for the insurance option.  Based on expert opinion for a reasonable coverage level, a 75% coverage level was applied.  A target yield (105 bushels per acre), indemnity payment ($2.00 per bushel) and premium ($9.68 per acre) were calculated for the current year, 2002, to maintain consistency for using the most recent data available.  The insurance data were incorporated into each year in the data set to evaluate the impact crop insurance could have on risk.

## Results

Results from this analysis are provided in Figures 3.1 through 3.4 and in Tables 3.1 through 3.5.  Results show that yield monitor data can be combined with expenses to create a series of risk maps to help the producer identify changes in temporal risk, spatially.  This section will provide

interpretation and insight into the meanings of these maps. This section will begin with a short discussion of the yield prediction procedure tests, followed by a discussion on the risk maps, with and without the crop insurance option.

Tests for the yield prediction procedure indicate that although yields were not perfectly predicted, the procedure did not unreasonably predict yields for the purpose of this study. Having three years of available yield monitor data, two years were required to estimate yields, leaving the third year available to test the prediction procedure. The adjusted $R^2$ between the estimated and the actual yield data for the third year was .3005, suggesting a poor capture of the actual yields. Using measures for bias and precision outlined in Mueller et al., the procedure was also shown to be somewhat biased, with a less than desired prediction efficiency.

These results offer two suggestions. One, the prediction procedure poorly estimated yields for one year. Because only one out-of-sample year was available for testing, conclusions for prediction efficiency cannot be drawn for every year in the study. Secondly, the overall objective of this study was to develop economic decision aids for risk management for users of PA. This objective is achieved through the creation of the various maps. While the prediction procedure has a direct impact on the results, the results of this study are not invalidated. Accounting for spatial variation has not been easily accomplished. According to Sadler et al. (2000), a study trying to predict corn yield, they discovered that classical statistics were not well suited for spatial problems. "The multitude of causes and effects operating to create spatial variation within a field poses a challenge to even the most advanced experts or simulation models" (p. 395). In their results, "little correlation was found among any simple combination of crop characteristics" (p. 401). Thus, while the information provided by these maps to the decision maker will improve with a better prediction estimator, finding this estimator is beyond the scope of this study.

Descriptive statistics for yields are provided in Tables 3.1 and 3.2. The annual mean, maximum, minimum, standard deviation, and CV of yields shown in Table 3.1 are based on the spatial yield monitor data collected from one field in 1996, 1998, and 2000. These statistics provide insight regarding the spatial variation within the one field used for analysis. One should note that the most spatially variable year was the year with neither the highest nor lowest field average yield.

The first two data columns of Table 3.2 are statistics for the farm level yield averages from the years 1981 through 2000, for both the actual yields and the detrended yields. These statistics convey the temporal variation for the entire farm. As explained earlier, yield monitor data and farm average yields were used to create spatial yield data for the entire twenty year period. Those statistics

are found in the last two data columns of Table 3.2.  The temporal yield statistics column is based on the annual field level yield averages of the entire twenty year period, while the spatial yield statistics are based on the yield averages per grid for twenty years, both given on a per acre basis. Data were not recreated for the three years in which actual yield monitor data was available.  In two out of the three recent years, the field used in this case study had average yields higher than the twenty year farm level average.  This should be expected given general trends of increasing farm productivity.

Figure 3.1 is the map of average net returns across the twenty year history.  The average net returns above variable costs across the entire field was $7,760.  As one can easily see, this is a rather profitable field.  With the exception of the field borders and a small number of interior grids, the entire field covers at least variable costs.  There are only 24 grids (.59 acres) that cover variable costs, but not fixed costs (shown by the yellow grids).

However, as the remaining maps illustrate, positive net returns does not imply a lack of risk. Figure 3.2 is the break-even probabilities map, showing the percent chance that each grid will break even, given the twenty year history.  While most of the field is in green, signifying a 100% chance of breaking even, the entire field is not represented as such.  The net returns map showed problems with field borders and the break-even map confirms this (the red and yellow areas).   Red areas had a 25% or less likelihood of breaking even.  This map also illustrates some riskiness in interior portions of the field (the blue areas).  However, there is still a high likelihood (80-95%) that most of the areas will break even.  Additional information on this map is presented in Table 3.3, showing the percent of the field in each of the break-even categories.

Figure 3.3 represents the spatial array of the coefficients of variation for net returns across the field.  Although the categorizations were chosen independently, results for the CV map and break-even probabilities map showed similar patterns.  Those areas with a less than 100% chance of breaking even have a higher CV.  Also, by definition of CV, grids with a negative average net returns will have a negative CV.  Again, field borders are revealed as the main problem areas, with interiors portions causing minor concerns.

The final risk map is the E-V map of net returns, Figure 3.4.  This map displays the areas that a producer of a certain risk aversion level may choose not to produce, given their break-even requirements.  The green areas would always remain in production and the red areas would never be in production, regardless of risk preferences.  These areas show consistent results with the previous maps.  Intuitively, as the producer becomes more risk averse, more land would be removed from

production, assuming that there is some risk in agricultural production. Table 3.4 can be reviewed for further information about this map. Statistics are calculated for the four risk aversion levels based on the producer's decision to remove grids with negative average net returns from production. There is a trade-off between net returns and risk. As Table 3.4 illustrates, as a producer's risk aversion level increases, of the land left in production, riskiness decreased, but so does average net returns.

Including crop insurance changed the results very little. The target yield to trigger an insurance payment was 105 bushels per acre. Only one year out of twenty averaged a yield less than the trigger. Thus, for nineteen years, the only change in net returns resulted from the producer's loss of the premium. The most noticeable change can be found in Table 3.3, showing the percent chance of breaking even. Receiving the indemnity payment for that one year slightly increased the percent of the field with 100% chance to break even. The net insurance benefit that year was only $0.40 per grid. This shows how close some of the grids originally were to breaking even.

Adding crop insurance had some impact on the decision to remove land from production among the various risk aversion levels, presented in Figure 3.5. For most of the field (90.17%), the decision did not change. However, in 5.23% of the field, where originally only a highly risk averse producer would chose to produce on those areas, adding crop insurance reduced risk enough to encourage production regardless of risk aversion levels. On the maps, these areas changed from blue in Figure 3.4 to green in Figure 3.5. In another 4.47% of the field, the decision not to produce was delayed one higher risk aversion level. For example, in Figure 3.4, a risk neutral producer would not produce on grid number 196. With the insurance option, a risk neutral producer would produce on that grid, however a low risk averse producer, being more risk averse than the risk neutral producer, would not.

The results from the crop insurance maps showed that this particular field, because of its productivity, would not effectively demonstrate the role crop insurance could have for risk management. Surprisingly, there were only two grids in the average net returns map that were affected by crop insurance. For every grid in the field, the difference in average net returns was only $0.60. The negligible impact was a direct result of using a highly productive field in this research. When only one year out of twenty triggers an insurance payment, there will be little effect. Given its production history, this field would likely not be enrolled in a crop insurance program to begin with.

Overall, these maps show that the chosen statistics can be used to identify risky areas of a field. The net returns map established that this is a profitable field. However, this map is just "the

cover" of the field, and as the remainder of the maps showed, there was more to the story. Managers do not manage according to net returns alone. Risk must also be managed, as it directly impacts net returns. After reviewing the risk maps, problem areas not identified by the net returns map appeared. If the producer went no further than the net returns map, many risky areas would be missed and net returns could potentially suffer. Consequently, the manager would not have the best information to make sound decisions. By including the risk maps into the decision-making process, more problem areas can be identified and managed accordingly. The producer can then find economically feasible remedies that could lower the riskiness of the field and further increase profitability.

These maps can also be used to compare production strategies. For example, would variable rate applications have an effect on risk? Would chemical resistant seed varieties reduce risk? By developing maps before and after implementing different production strategies, these maps can further improve farm management decisions.

## Conclusions

For several years, many farmers have been collecting a large amount of yield monitor data with PA technologies. However, relatively few economic decision aids have been available to help these producers make economic decisions with this data. This study has shown that with the combination of yield maps and production expenses, a series of risk maps can be created to identify spatial risk across a field. Using these maps, producers can now begin to address the underlying issues creating this spatial risk.

The importance of creating risk maps is that the producer can then make decisions based on that knowledge. In this field, for example, some of the field borders were both highly risky and unprofitable. This producer may be better off not planting these areas and leave them as field access strips. If these areas are eligible, they could be enrolled in the Conservation Reserve Program (CRP). However, the objective of this research was not to give producers the solutions to the problem areas identified in the field. The objective was to use PA data to identify problem areas and use such information for economic decision tools. The identification of problem areas is only the first step in the decision-making process. It will be up to the producer to decide on the best course of action.

This study raised some important issues in using yield monitor data for research. In most PA studies, the data was collected with the specific study in mind, with special attention paid to the

quality of data collected.  However, this study was completed with data collected by a farmer, as a farmer would collect it.  If decisions are going to be made using PA data, this is the type of data that will be used in the decision-making process.  It will not be a perfect data set.  Some producers may pay closer attention to the calibration and maintenance of their yield monitors than other farmers.  Hopefully, the sooner farmers begin using yield monitor data for decision-making, the sooner they will discover any errors and can take corrective actions to improve future decisions.

One of the concerns in this study was the derivation of the unavailable yield maps.  As discussed earlier, the test of the prediction procedure showed less than desirable results.  This leaves two options.  One, developing a better yield prediction procedure.  Or, two, determine if a prediction procedure is needed.  Would using the three years of actual yield monitor data have been good enough to make long-term decisions?  For this study, in mapping only the three years of data, while the magnitude of the problems areas differed, similar risk patterns were identifiable.  Considering that more than three years are generally desired for long term planning and waiting the ten to twenty years it would take to collect actual data, some type of prediction process will have to be used.  Although the prediction procedure used in this study may not be perfect, it is an important first step.

The objective for developing decision aids is to make them available to those who can use them, in this case, for users of PA.  The next step in the process is the development of a vehicle to make this a reality.   One possibility is a web-based economic advisory service to which producers can send the relevant data, such as yield maps and relevant costs.  The service would then send maps back to the producer.  The information and skills developed through this study can be used to create a pilot project.  This pilot project will help address the issues involved for opening this service to users of PA.

Table 3.1.  Descriptive spatial statistics from yield monitor data across grids for years available (bushels per acre).

| Year | Mean | Maximum | Minimum | Standard Deviation | Coefficient of Variation |
|------|------|---------|---------|--------------------|--------------------------|
| 1996 | 178.4 | 295.1 | 9.5 | 37.6 | 21.0% |
| 1998 | 150.8 | 263.4 | 11.0 | 45.9 | 30.4% |
| 2000 | 130.8 | 249.6 | 9.8 | 32.4 | 24.7% |

Table 3.2.  Descriptive statistics of farm level average yields and estimated yield monitor data from 1981-2000 (bushels per acre).

| Statistics | Farm Level Average Yields[1] | | Estimated Yield Monitor Data | |
|------------|------------------------------|--|------------------------------|--|
| | Actual | Detrended | Temporal[2] | Spatial[3] |
| Mean | 128.5 | 143.6 | 145.6 | 145.6 |
| Maximum | 168.0 | 184.4 | 184.4 | 238.8 |
| Minimum | 79.0 | 97.5 | 97.5 | 17.5 |
| Standard Deviation | 19.31 | 19.1 | 20.4 | 29.7 |
| Coefficient of Variation | 15.0% | 13.3% | 14.0% | 20.4% |

[1]. Farm level average yields are temporal averages, based on the twenty years of historical yields.
[2]. Temporal yield data are based on the annual field averages for 20 years.
[3]. Spatial yield data are based on the yield averages per grid for 20 years.

Table 3.3.  Percent of field in break-even probability categories, with and without insurance.

| Percent chance for net returns above breakeven | Percent of Field (No Insurance) | Percent of Field (With Insurance) |
|------------------------------------------------|----------------------------------|-----------------------------------|
| 0 - 25% | 2.77% | 2.90% |
| 30 - 50% | 2.08% | 2.08% |
| 55 - 75% | 2.14% | 2.08% |
| 80 - 95% | 12.98% | 10.65% |
| 100% | 80.03% | 82.29% |

Table 3.4. Descriptive statistics for E-V map.

| Risk Aversion Level | Percent of Land in Production | Mean Net Returns | Net Returns Coefficient of Variation (%) |
|---|---|---|---|
| Full Production | 100% | $7,760 | 38.8% |
| Risk Neutral | 96.03% | $7,852 | 25.5% |
| Low Risk Averse | 92.25% | $7,769 | 23.8% |
| Medium Risk Averse | 87.65% | $7,502 | 22.5% |
| High Risk Averse | 79.33% | $6,876 | 20.6% |

Figure 3.1: Net Returns Above Costs Map, 20 year average.
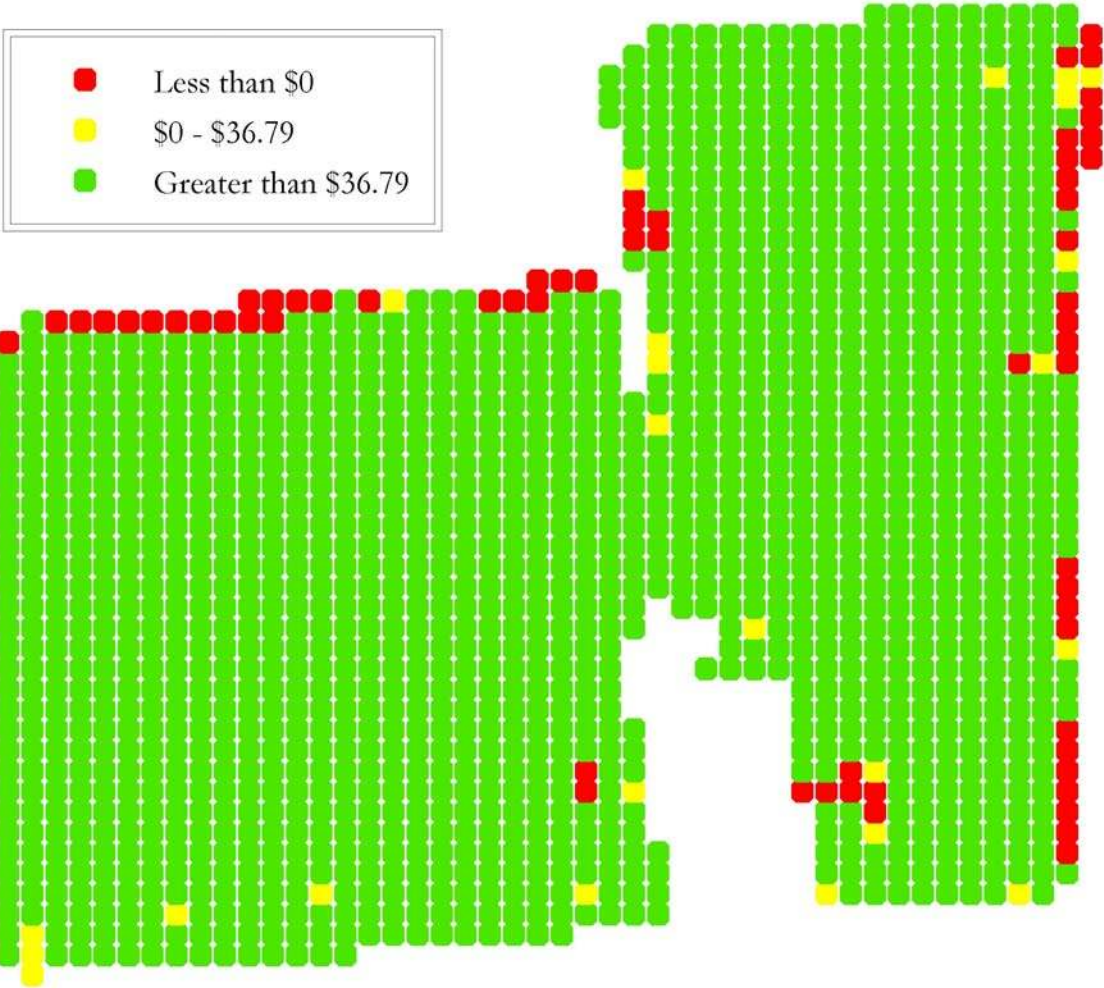


Notes: Red areas are negative net returns. Yellow areas are positive returns above variable but not fixed costs. Green areas are positive net returns above total (variable and fixed) costs.

Figure 3.2: Break-even Probabilities Map for 20 year average of net returns.
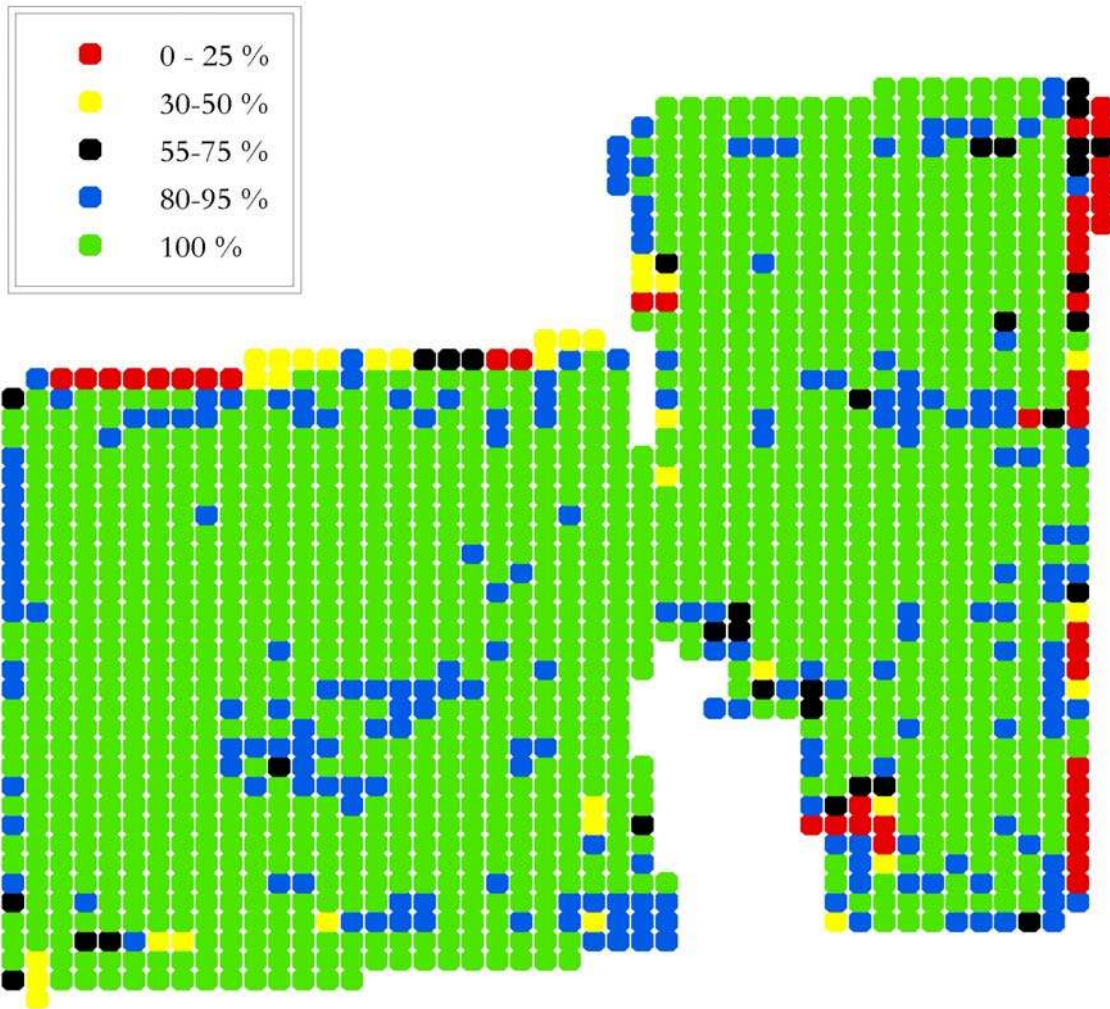


Notes: This map illustrates the percent chance that each grid will break even, based on its 20 year production history.

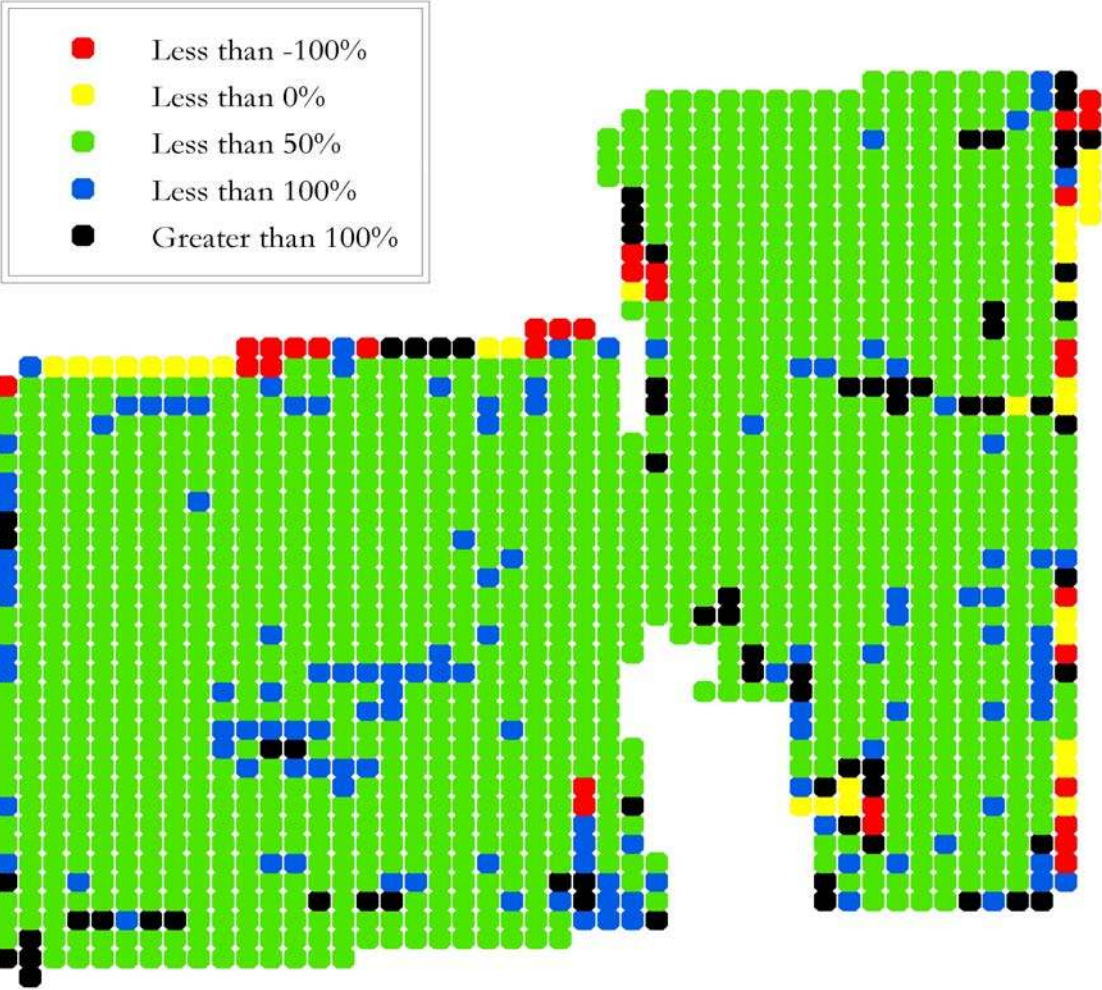Figure 3.3: Coefficient of Variation for 20 year net returns average.

Figure 3.4: E-V Risk Map of 20 year average net returns, decision not to produce.



Notes: Green areas would always remain in production. At any risk aversion level, production is not justified in the red areas. A low risk averse producer would not produce in the yellow or red areas, a medium risk averse producer would not produce in the black, yellow, or red areas, and a high risk averse producer would not produce in the blue, black, yellow, or red areas.
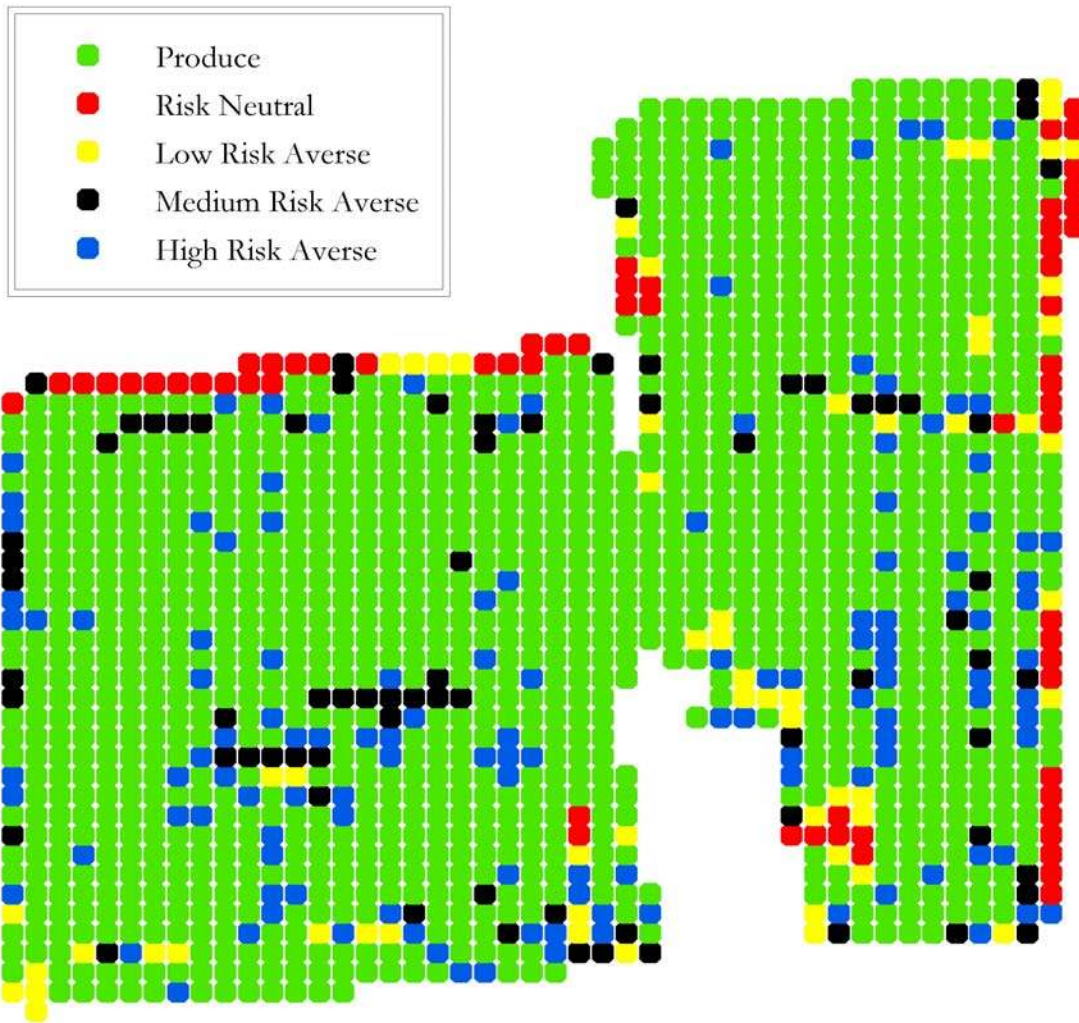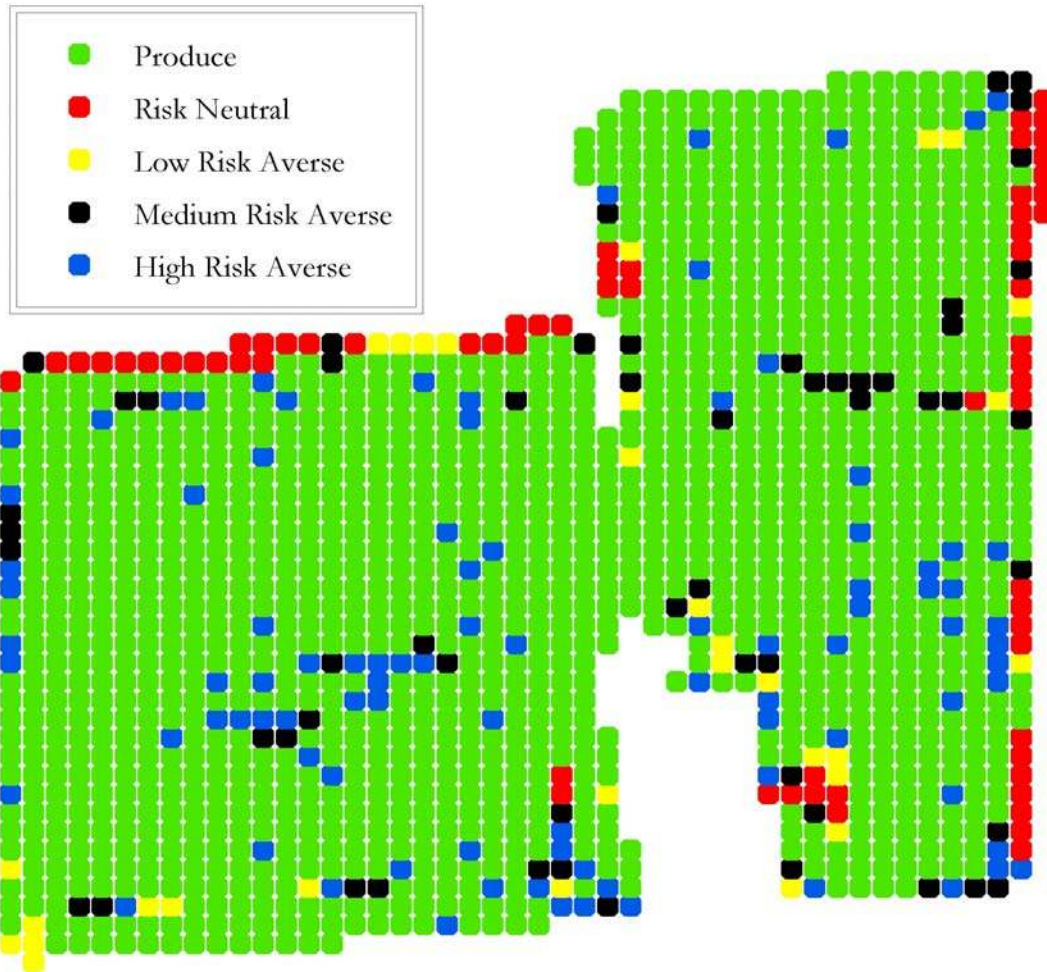
Figure 3.5: E-V Risk Map of 20 year average net returns, with crop insurance, decision not to produce.



Notes: Green areas would always remain in production. At any risk aversion level, production is not justified in the red areas. A low risk averse producer would not produce in the yellow or red areas, a medium risk averse producer would not produce in the black, yellow, or red areas, and a high risk averse producer would not produce in the blue, black, yellow, or red areas.

## Endnotes

1. In 1999, agriculture was the third highest fatality rate among all occupations (Bureau of Labor Statistics).

2. The prediction procedure was established based on the following linear relationship,

$$Yld_{t,g} = \beta_{0,g} + \beta_{1,g} Yld_{Fmavg,t},$$

where $Yld_{t,g}$ = the farm average yield in time period, t, for grid, g, and

$$\beta_{1,g} = \frac{Index_{1,g} - Index_{0,g}}{Yld_{1,fdavg} - Yld_{0,fdavg}},$$

where $Yld_{Fdavg}$ = the field average yield in time period, t per grid, g, and

$$\beta_{0,g} = Index_{1,g} - \beta_{1,g} * Yld_{1,Fdavg}.$$

The index per grid is calculated by,

$$Index_{i,g} = \frac{Yld_{i,g}}{Yld_{i,Fdavg}} * 100$$

where, i=0 for minimum Fdavg and i=1 for maximum Fdavg.

# Chapter Four

# Conclusions

This thesis has examined the use of precision agriculture (PA) data, specifically yield monitor data, for agricultural decision making. It has done so through two separate, yet complementary scientific articles. The first article explored the use of PA data for identifying areas of a field which a producer may choose to remove from production. This decision was based on the break-even point between site-specific costs and returns. Included in this decision was the role that a producer's risk aversion level and land tenure arrangement played in the decision-making process.

The second article, also dealing with site-specific costs and returns, examined how yield monitor data could be used to create risk maps. Risk maps were developed showing the temporal variation in risk spatially across a field using break-even and mean-variance analysis and the coefficient of variation. These maps were modified by comparing how risk would change had the producer been involved in a crop insurance plan, a common risk management strategy.

These two articles complement each other by illustrating that PA data can be used to make site-specific economic decisions for the farm business. Most of the PA literature available has focused on the production side of the technologies. While PA is inherently about the technologies, it does not end with the technologies. PA realistically allows the producer to collect more site-specific agricultural data than ever before. The evolution of PA cannot be complete until farmers close the loop from using the technologies to collect information to making profitable decisions for the farm business.

This research has made many contributions to the area of PA research. The primary contribution was in achieving the overall purpose of the thesis by developing decision tools for PA practitioners. As stated in the previous chapters, few decision aids have been developed using such data, and the need for these tools has been identified as a weakness in PA. These two articles are a first step in providing producers the tools to close the loop in making decisions with PA data.

This research has shown that while yield maps alone cannot be used to make management decisions, they can contribute to the decision making process. One of the most misleading maps presented in PA literature is a "profit map"; in the past this phrase has often been misused. Actual profit is not found until all costs have been accounted for, including capital and management. Managerial worth is especially difficult to measure, spatially or otherwise. What unit would one use to value management: dollars per acre, dollars per hour, dollars per change in production for a given

area?  Does a manager spend more time managing the more productive areas of the field or the less productive areas?  Or, is their time spent equally across the entire field?  While the phrase "profit map" may still be used, one must keep in mind that these maps are more correctly labeled net returns maps, as suggested in Chapter Three.

The creation of risk maps is a new contribution to PA literature.  The use of PA as a risk management tool is relatively new.  Although a small number of sources discussed this aspect of PA, many of these have, again dealt specifically with the risk associated with the technologies.  For example, the Cook et al. study mentioned in Chapter Three compared the risk across different variable rate application options.  The purpose of Chapter Three of this thesis was to assess risk over the entire production process by using net returns as the risk indicator.  If a producer can identify how risk varies across a field, then management decisions can be made to either profitably correct the problem areas or to minimize their effects on profitability.

The feasibility of using yield monitor data for decision-making was another contributed result from this research.  The quality of the decision maps presented in this study depend on the availability of usable yield monitor data.  The process of turning the original yield monitor data into a usable form is a multi-stage process.  As discussed in Chapters Two and Three, before yield monitor data can be used, it must be free of errors, indexed with weigh scale tickets, converted from point data to grid data (with the grids coinciding each year), and missing grid data must be estimated. Farmers must have the necessary computer programs and be well versed in those programs to complete this initial process.  Ideally, however, a computer program could be developed to automate this process, resulting in little time and knowledge investment for the producer.

The use of a yield prediction procedure was outlined and briefly discussed in Chapters Two and Three.  Also as discussed in Chapter Three, preliminary tests for this prediction procedure showed a poor predictive ability.  Only three years of yield monitor data were available for this study.  Two of the years were used in the prediction procedure, leaving only one out-of-sample year to test the procedure.  Although yields were poorly predicted for this one year, perhaps yields were more accurately predicted in other years.  This however, could not be tested because actual yields for those years were unknown.  Although the accuracy of the prediction procedure directly impacts the results of this study, a thorough testing of the procedure was beyond the scope of this study.

With the results of this prediction procedure being less than ideal, three options are available for PA data's potential for strategic decision making.  First, a better prediction procedure could be developed.  The goal in developing the procedure for this study was to create a simple procedure,

where temporal variability could be indexed using a single crop or weather characteristic that could be easily reproduced for other PA practitioners. It was concluded that farm yield averages could be the best indicator of temporal variability, and these averages should be readily available for every producer. However Chapter Three disproved this assumption. Unfortunately, the literature for the possibility of a simple prediction procedure is not encouraging. As discussed in Chapter Three, Sadler et al. concluded that little correlation was found between any single crop characteristic and yield. Again, although a thorough review of prediction procedure possibilities was beyond the scope of this study, research suggests that the likelihood of developing a simple prediction procedure is low.

The second option for using PA data for strategic decision making is to use only the existing data. More confidence is generated when long term decisions are based on several years of data. While the appropriate number of years needed for these decisions may be an arbitrary number, three years may not be enough. However, as briefly mentioned in Chapter Three, maps based on three years of data showed similar results as those based on the entire twenty years of data. Still, the more years involved in the decision-making process the better.

Finally, the third and perhaps least feasible option would be to wait the ten to twenty years necessary to collect enough yield monitor data before making decisions. While the third option should not necessarily be recommended by itself to make decisions, as new yield monitor data are collected, producers should include the new data in their analyses and monitor any changes that should be made in their decisions.

Throughout this research, thoughts regarding the psychology behind PA decisions developed. The maps from Chapters Two and Three show that both fields were very productive fields. For example, in the owned land, risk neural situation in Chapter Two, only a small percent of the field was economically justified to remove from production. In the average net returns map in Chapter Three, very few grid cells had net returns less than zero. These fields were chosen for research because they were among the few fields with three years of data available. They were not chosen because of productivity. This producer monitored many other fields, but data for these other fields were incomplete. If farmers choose which fields to monitor, how do they make that decision? Do they choose the fields believed to be the most productive? Or do they choose the fields they think to be the most spatially variable? Although no research is available, intuition suggests that farmers want to see how productive those good fields are, thus, these are the fields chosen for yield monitoring. However, research has suggested that the fields with the most to gain

from PA technologies are those with the most spatial variation. Including crop insurance in the Chapter Three was further illustration of this situation. Because this field was quite productive and showed little variation, including crop insurance added little to the results. Using maps like those developed here, farmers can verify if their productive fields are also profitable, and then spend more time working with the more spatially variable fields.

Using yield monitor data for decisions may also give farmers a reason to pay closer attention to the data collection process. Decisions are only as good as the information from which they are based. If the data have not been used beyond developing yield maps, the quality of that data may not be a good as expected. If the data have not been filtered as outlined in Chapters Two and Three then those yield maps may over or underestimate yields. Also, yield monitor data can be collected at different intervals. The data used in this research were collected at one, two, and three second intervals. Unless data storage space is in limited supply, the marginal cost of collecting data every second rather than every two or three seconds is low, but the potential benefit is great. Collecting yield data every second increases the number of points in the data set. This could result in having fewer holes in the data and lessen the need for the nearest neighbor approach, thereby eliminating a step which replaces actual yield with estimated yield across the entire field.

The development of these decision maps can lead to further research in PA. First, a more thorough review of the prediction procedure is warranted, as previously mentioned. Secondly, variable rate technology (VRT) was not included in the analysis. This producer did not employ VRT on the farm. The inclusion of VRT will make the expenses more site-specific. Similarly, more research can be completed on calculating other costs site-specifically. The accuracy of net returns maps depend on the ability to accurately calculate expenses per grid. For example, if the crop is planted at a single rate, then the seed expense will be equal for each grid. However, with chemical applications, there will likely be some level of overlap of the chemical. Thus, the chemical expense per grid will not be equal. If the producer spot sprays the fields, those expenses must be recorded and geographically referenced. In this research, with the exception of those costs believed to be related to yield, such as fuel and oil, all other expenses traditionally calculated on a per acre basis were expensed equally for each grid.

Creating a replacement nearest neighbor approach is another area where this research can be improved. As previously discussed, after converting point data to grid data, there may be grid cells with no data. Because this portrays an inaccurate picture of the production in the field, a nearest neighbor approach was used to estimate yields for those grids. This procedure assigned yields to the

missing grid cells with the yield of the nearest grid cell.  The problem with this procedure is that values are assigned to every grid, not just those with missing data.  The effectiveness of this procedure depends on how many grids are missing and how spatially variable yields are.  The more grids that are missing and the more spatially variable the yields, the less accurate the resulting map will be.  A procedure that would assign values to only the missing grids would correct this problem.

These maps can help the producer in conducting their own field trials.  Most field trials report productivity differences in varieties.  The same methods used to calculate the risk maps can be incorporated with field trial data to examine net returns and risk of different seed varieties. Farmers can overlay these maps with VRT as-applied maps, soils maps, or remote sensing maps to complete their own farm experiments.  They would be able to answer questions such as how do the different soils affect profitability and risk.  They can compare pre-VRT applications to post-VRT applications to see if any changes to profitability or risk have occurred.  If the bottom line in the farm business is how decisions affect profitability and risk, the ability of the farmer to visually see how they change can allow the producer to see how different production practices also affect profitability and risk.

Another area for future research was derived from adding the crop insurance option in Chapter Three.  Results from this Chapter showed that, because the high productivity of the field, crop insurance did not lower risk.  Crop insurance is based on a trigger yield, identified on average yield data across an entire field.  For a field as productive as the one used in this research, crop insurance would not be an option.  However, would the results have changed if insurance payments were based on grids within a field instead of just the entire field?  Perhaps development of spatial crop insurance program could be used in fields with great spatial variability.

The final point for consideration in this research is how these maps can get into the hands of those that can use them, other PA practitioners.  Chapters Two and Three briefly discussed the development of an economic advisory service administered through the Internet as a way to make these tools available to farmers.  Providing such a service is especially relevant considering the process of getting data into a usable form.  Farmers would send the service their yield maps and other relevant information, then the service would compile the maps.  A paper was presented by this author at the Southern Agricultural Economics Association annual meeting in February 2002 addressing this issue.   Although several issues were identified to be addressed, including speed of internet connection capabilities at the farm as well as those issues identified here regarding the prediction procedure, it was concluded that the development of an web-based, economic advisory

service for users of PA appeared favorable.

The use of precision agriculture has gained popularity in Kentucky over the past decade. Although there is a great deal of information provided through these technologies, making decisions based on this information has not always been clearly defined. In the words of a producer involved with precision agriculture, "'Precision farming is like a road map: there's a lot of dead ends, and a lot of roads under construction. Farmers want answers in black and white; precision farming gives answers in 256 shades of gray'" (Gibbons, p.4). While the use of PA technologies will not give farmers the decisions they need to make, it gives them the tools from which they can collect and analyze information from which their decisions are based.

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**Education:**  **University of Kentucky**, Lexington, Kentucky

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**Service Activities:**

**College of Agriculture,** University of Kentucky, Search Committee for the Dean of the College of Agriculture.  June 2000 to Present.

**Judge, 4-H State Talk Competition**, Cooperative Extension Service, May 19, 2000.

**Graduate Student Organization**, Department of Agricultural Economics, University of Kentucky, Treasurer.  August 1999 to Present.

**College of Agriculture**, University of Kentucky, Periodic College Review Committee Member.  October 1999 to April 2000.

**Department of Agricultural Economics**, University of Kentucky, Periodic Departmental Review Committee Member.  October 1997 to February 1998.

**CERES Association**, Women's Agricultural Fraternity, Treasurer and Chapter Charter Member.  April 1997 to Present.

**Awards:**

**Epsilon Sigma Phi, Tennessee State Team Award** for the Sustainable Dairy Systems Manual Training.   November 1998.

**American Agricultural Economics Association**, Student Section, 1997 Quiz Bowl Championship Team.

**American Agricultural Economics Association**, Student Section, 1996 Quiz Bowl Championship Team.

**Numbered Publications:**

Powers, Laura, Steve Isaacs, Tim Woods, John Strang, Brent Rowell, Dave Spalding, Terry Jones,

and Winston Dunwell. **Horticultural Crop Enterprise Cost and Return Estimates for 1998**. ID-99.  Univ. of Kentucky, College of Agric.  June 1998.

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Powers, Laura and Will Snell.  **The Kentucky Agricultural Economic Outlook for 2001.**  Univ. of Kentucky, College of Agric.  November 2000.

Powers, Laura and Will Snell.  **The Kentucky Agricultural Economic Outlook for 2000.**  Univ. of Kentucky, College of Agric.  November 1999.

Powers, Laura.  **The Proceedings of the 38th Tobacco Workers' Conference**.  Univ. of Kentucky, College of Agric.  November 1998.

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## Other Publications:

Powers, Laura, Steve Isaacs, Richard Trimble, and Leigh Ann Penn.  **Experiences with Compulsory Farm Management Trainings for High Risk Farmers**.  Published Proceedings from the 12th International Farm Management Association Congress, Durban, South Africa.  July, 24 1999.

Trimble, Richard, Laura Powers, Steve Isaacs and Geri Isaacs.  **Educational Innovations in Teaching Financial Record Keeping to Farmers**. Published Proceedings from the 12th

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Dillon, Carl, Gregg Ibendahl, Steve Isaacs, and Laura Powers. **Economic Analysis of Roundup Ready® Soybean Programs**. Supporting Documentation for the Roundup Ready® Decision Aid. July 1999.


## Computer Software Programs:

Powers, Laura and Steve Isaacs. **Farm Financial Analysis Ratios Baled Software**. March 2002.

Powers, Laura, Steve Isaacs, and Richard Trimble. **Field Crop Enterprise Cost and Return Estimates for Kentucky, Version 3.0**. October 2001.

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Isaacs, Steve and Laura Powers. **Precision Farming Worksheet**. October 1998.

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## General Extension Meetings:

Isaacs, Steve, Laura Powers, and Alison Smith. **Master Cattlemen's Management Skills Session**. Paducah, KY. August 26, 2002.

Isaacs, Steve and Laura Powers. **Master Cattlemen's Management Skills Session**. Burkesville, KY. August 12, 2002.

Isaacs, Steve and Laura Powers. **Master Cattlemen's Management Skills Session**. Russellville, KY. June 25, 2002.

Isaacs, Steve, Jack McAllister and Laura Powers. **Master Cattlemen's Management Skills Session**. Lexington, KY. June 20, 2002.

Powers, Laura, Alison Smith, Mike Smith and Vicki Shadrick. **Master Cattlemen's Management**

**Skills Session**. Henderson, KY June 3, 2002.

Trimble, Richard and Laura Powers. **Computer Software for Farm Record Keeping**. Burkesville, KY. January 28, 2002.


**Multi-Session Workshops:**                                        *58 since 1998*

*examples include:*

Isaacs, Steve, Richard Trimble, Laura Powers, Gregg Ibendahl, and Colby Blair. *UK Farm Management Workshop*. Farm Service Agency Borrower Training Program. Lexington, KY. August 6 & 7, 2002.

Trimble, Richard L., Laura Powers, and Steve Isaacs. *Quicken Recordkeeping Workshop*. Muhlenburg Co., KY. Evening sessions November 14, 15, & 16, 2000.

Isaacs, Steve, A.J. McAllister, Laura Powers, and the Extension Agents of the Green River Area. *Management 1ˢᵗ Workshops*. Henderson and Owensboro, KY. February 26 & 27, Mar. 4, 1998.

Isaacs, Steve, Clark Garland, and the Sustainable Dairy Systems Team. **Southern Region training with the Sustainable Dairy Systems Manual and Software**. Charlotte, NC. September 21-23, 1998.


**Agent In-Service Training:**                                        *17 since 1998*

Isaacs, Steve, Laura Powers, Gregg Ibendahl, and J.D. Green. **Computerized Farm Decision Aides**. Pennyrile State Park. December 19-20, 2000.

Trimble, Richard and Laura Powers. **Farm Financial Statements Workshop**. Lexington, KY. November 29, 2000.

Isaacs, Steve, Jack McAllister, Sue Badenhop, et al. **Farm Family Financial Management Training**. Lexington, KY. November 14-15, 2000.

Trimble, Richard, Laura Powers, Steve Isaacs, and Greg Ibendahl. **Quicken Recordkeeping Workshop**. Lexington, KY. November 1, 2000.

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Isaacs, Steve and Laura Powers. **Using and Teaching Farm Financial Statements**. Virginia

Area Farm Management Specialists.  June 14, 2000.

Trimble, Richard L., Laura Powers, and Steve Isaacs.  **Quicken Recordkeeping Workshop**.  Princeton, KY.  November 1, 1999.

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Isaacs, Steve, Jack McAllister, Sue Badenhop, et al.  **Farm Family Financial Management Training**.  Lexington, KY.  August 31, 1999.

Wells, Ken, Steve Isaacs, and Laura Powers.  **Farm Planning Tool In-Service.**  Richmond, KY.  March 29-31, 1999

Trimble, Richard L., Laura Powers, and Steve Isaacs.  **Quicken Recordkeeping Workshop**.  Princeton, KY.  November 16, 1998.

Trimble, Richard L., Laura Powers, and Steve Isaacs.  **Quicken Recordkeeping Workshop**.  Lexington, KY.  November 18, 1998.

Isaacs, Steve, Richard Trimble, Gregg Ibendahl, Carl Dillon, John Anderson, Darwin Foley, Rush Midkiff, Russ Morgan and Laura Powers.  **Farm Financial Survival in the Current Farm Crisis**. Economic Subject Matter Meetings.  Perry, Harrison, Franklin, LaRue, and Caldwell Co., KY.  October 19-23, 1998.

Meyer, Lee, Steve Isaacs, John Anderson, and Laura Powers. **Spreadsheet Templates for Decision Making**. Lexington, KY. October 7, 1998.

Isaacs, Steve and Laura Powers. **Management 1st In-Service for Green River Area Agents**. Ohio Co., KY. Jan. 23 and February 20, 1998.


**Professional Presentations:**

McAllister, Jack and Laura Powers.  **SMART Goals for Success, Kentucky 4-H Volunteer Forum**.  Lexington, KY.  February 22, 2002.

Powers, Laura A.  "Development of a Decision-Making Advisory Framework for Users of Precision Agriculture: A Production/Nonproduction Decision Example."  Paper presented at Southern Agr. Econ. Assoc. annual meeting. Orlando FL, 2-6 February 2002.

Powers, Laura.  **Basic Tools for Farm Record Keeping**.  Kentucky Women in Agriculture, Fayette County Extension Office.  January 18, 2001.

Powers, Laura.  **SMART Goals for Success**.  Kentucky Youth Seminar Program.  June 22, 2001.

Powers, Laura.  **The Tobacco Budgeting Comparison Program**.  39th Tobacco Workers'
  Conference.  Williamsburg, VA.  January 2000.

Powers, Laura.  **Computerized Decision Aids**.  The Farm Family: Business in Transition.
  Bluegrass Extension Area, Lexington, KY.  November 17, 2000.

Powers, Laura.  **Experiences with Compulsory Farm Management Trainings for High Risk
  Farmers**.  12th International Farm Management Association Congress, Durban, South
  Africa.  July, 24 1999.


**Professional Meetings:**

**Southern Agricultural Economics Association, Annual Meetings.**  February 2002.

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