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An economic evaluation of using Management Zones in cotton production

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AN ECONOMIC EVALUATION OF USING MANAGEMENT ZONES IN COTTON PRODUCTION

A Thesis

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
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by

Jose A. Cabrera-Davila
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ABSTRACT

This thesis examines the use of Precision Agriculture technologies to define Management Zones within a multicrop production system. It further evaluates the economic feasibility of implementing spatially variable insecticide applications against conventional blanket treatments with respect to insect pest management in cotton production. The use of geographical information systems was critical in the development of the different yield maps established to determine the level of consistency of management zones across crops over time. Several important concepts, such as data normalization, yield grid maps, inverse distance weighted and stability, were introduced throughout this research to: set the scale of measures to the same basis, facilitate comparison across crops, manipulate the data, and establish a level of confidence, respectively, concerning the use of management zones in crop production. Furthermore, the basic notion behind this study was that if fields can be divided into high/low yielding management zones, the use of variable rate technology, through an ON/OFF prescription application, offers the potential to reduce costs and increase productivity of the field. The capital recovery method was used to evaluate the per acre cost of investing in a precision farming system for gathering site-specific information and performing SVI applications. Results from this study show that the use of yield-based management zones can reveal annual cost reductions and increased profitability for the producer.

KEYWORDS: Precision Agriculture, Spatially Variable Insecticide Applications, GPS/GIS, Crop Rotation, IDW, Yield Monitors.
CHAPTER 1
INTRODUCTION AND RESEARCH OBJECTIVES

Introduction

Understanding the benefits of new technologies, such as Precision Agriculture (PA), is still far from perfect, but gradually some producers are beginning to recognize the advantages PA offers to their operation. Doerge (2000) describes PA as “collecting and controlling agronomic information to supply actual needs to parts of fields rather than average needs to whole fields.” For many producers, the advantages of using PA are obvious: characterizing variability within the field, tailoring inputs to match specific needs, and improved environmental stewardship.

Traditionally, farming practices, such as fertilization, tillage, cropping and pest management, were defined uniformly for each field. In the present day, PA takes into account within-field variability to enable the precise targeting of activities, such as crop spraying or fertilizer application, only when and where they are needed (Lambert and Lowenberg-DeBoer, 2000). PA practices, therefore, have the dual advantages of maximizing production and helping to minimize environmental damage.

With the increasing complexity of farming, producers are exposed to elevated risk. Under these conditions, managers need improved information technology, greater information processing capability, and better decision aids. Precision Agriculture provides measures for tailoring production inputs to specific plots within a field, thus potentially reducing input costs, increasing yields, and reducing environmental impacts by closer matching of inputs to crop needs (Heimlich, 1998).

Information technologies used in precision agriculture cover four aspects of production: data collection or information input, analysis or processing of the precision
information, interpretation of the results, and recommendations or application of the information. Examples of the use of these technologies will be incorporated throughout the literature review section of this thesis. Ideally, soil data or yield data could be used to develop application maps for each crop input. Based on these maps, a sprayer or spreader could be operated to apply the precise amount of the input where it is needed. The development of precise application maps for crop inputs can be extremely difficult and costly, especially in areas where soil variability and pest infestation is high. Research suggests however, that it would be better to recognize areas that have different yield potential (and therefore management requirements), but which may be managed uniformly within defined boundaries. These delineated areas would be managed differently from the rest of the field, but always in accordance with their own yield potential (each subunit having a different yield potential). Called Management Zones, these areas are essentially small fenceless fields within much larger fields.

The degree of accuracy with respect to spatial information regarding the optimal level of input (e.g., pesticide) is desirable on as fine a scale as feasible. However, the fixed cost per zone (e.g., soil sampling, GPS, yield monitors) associated with this greater accuracy will not, at some point, justify the additional costs of this marginal scale of management. The decision to delineate economically optimal Management Zones represents an opportunity to assist producers in achieving the combined goals of profit maximization and risk management.

This study will incorporate information gathered from a multi-disciplinary project conducted by a multi-institutional team under the leadership of scientists at the Louisiana State University Agricultural Center. The study will focus on evaluating the profitability
of precision agriculture in cotton production through comparing the efficacy of using spatially variable insecticide/defoliation technologies (SVI) against conventional (blanket) whole-field treatments based on the accurate identification of management zones (high/low yield points within a field) that are expected to be consistent across crops over time.

**Problem Statement**

Agricultural producers are experiencing an increasingly severe cost/price squeeze. Agricultural prices have been at record low levels while inputs costs have continued to increase. In an attempt to mitigate the negative impacts of these circumstances, farmers are looking for opportunities to reduce per-unit production costs. One such opportunity utilizes recently developed technologies that combine variable rate application of inputs with remotely sensed data.

Farmers are continually searching for more efficient and effective ways to manage production. Recent changes in agricultural programs make crop rotations a more viable alternative for many cotton producers. Also, recent advances in precision agriculture technology make it possible to record geo-referenced yield data for cotton. Yield monitors for grain crops have been available for a number of years. The problem addressed in this study is to determine if it is possible to identify areas of a field that are consistently high or low yielding across crops. Further, if such areas can be properly identified and analyzed, is it possible to modify input levels to increase profitability.

One of the main aspects of this study is using yield monitor data to define PA Management Zones. A Management Zone is defined as an area with similar yield potential. Currently, many of these Management Zones receive similar treatment when
with given agronomic recommendations, each area should be managed differently. Where technically feasible, yield monitors may provide a less expensive way to define these geographic units.

A very important related consideration is whether or not these zones are consistent across crops over time. For example, this is critical when analyzing crop rotations in a field because producers will want to know if a certain Management Zone can maintain the same yield ranking (stability) next year if, instead of soybeans, producers decide to plant cotton.

Though some agronomic analysis of Management Zones has occurred, there is a need for more information on the economic performance of Management Zones in PA. Potential advantages of these data collection and analysis processes include: higher yields, lower farm input costs, greater net farm income or profits and the environmental benefits from applying fewer agrichemicals. PA minimizes the likelihood of over-application or under-application of inputs because input levels are not based on average conditions within a field. Inefficient use of inputs can cause producers to lose money and the environment to suffer. This idea of “farming by the inch” provides a better understanding of the many factors that affect yields and profitability (Segarra, 2002).

This research will evaluate the profitability of implementing a management zone system that could increase cotton yields, reduce input usage and lower production costs. It will also aim to develop a better understanding of yield variability within a field and to perform economic analysis comparing conventional plant protection strategies to variable rate technologies (VRT) through the use of Geographic Information Systems (GIS) procedures.
Justification

One of the most important factors for the successful implementation of a PA strategy is to accurately identify Management Zones. These are defined as “the regions of a farm field that have been differentiated from the rest of the field for the purpose of receiving individual management attention” (Watermerier et al. 2000). Thus, the economic impact of this system will ultimately depend on the ability of producers to divide their fields into different Management Zones based on production potential and nutrient supply of their soils. Through an appropriate implementation of these management aids, producers should experience: improved profits, higher yields, cost savings through better allocation of inputs, and greater accuracy in decision making.

If fields can be divided into management zones, the use of variable rate technology as applied to input usages offers the potential to reduce costs and/or increase productivity of the field. Cost reductions might occur through reduced levels of inputs in certain management zones based on crop response to the input in that zone. Similarly, production might be increased by applying more input in other zones based on crop response. In either case, inputs can be applied based on marginal cost/marginal return principles to sub areas of the field. By maximizing profits on a sub-field level, profits for the whole field are improved, compared to applying inputs based on averages for the whole field.

Maximizing economic returns from a given field relies on our ability to readily assess field variability and use this information to calculate optimal rates of application of inputs. Well-targeted management zone delineations can provide this information at a fraction of the cost of whole-field sampling.
Research Objectives

The overall objective of this study is to determine a consistency in delineating Management Zones within a multi-crop production system using yield monitor data and through this, evaluate the economic feasibility of performing pest management strategies in cotton through the use of spatially variable insecticide applications (SVI).

Specific objectives of this study are:

1. To delineate Management Zones using yield monitor data.
2. To determine the consistency and reliability of Management Zones across crops over time.
3. To assess the potential impact on farm profits by comparing conventional plant protection strategies to strategies based on precision farming technologies in cotton production.

Thesis Outline

The first chapter will present the introduction, problem statement, justification for the research, and objectives of this research. The second chapter will provide a review of literature of the use of Management Zones in Precision Agriculture, technologies that combine variable rate application of inputs with remotely sensed data, and economic analyses of these techniques and technologies. Chapter three will incorporate the data and describe the procedures for this research with an emphasis on the application of Geographic Information Systems (GIS) in today’s farming as well as the economic methodology for the study. Chapter four will present the results and economic implications. The final chapter will provide the summary and conclusions of the research.
CHAPTER 2
REVIEW OF LITERATURE

Approach

Information gained from previous research serves to establish a basic framework for the proposed study. This section will provide background information on Precision Agriculture and explore the numerous areas of research involved in its development. Studies described include: Variable rate technology with respect to insect pest management in Cotton, Grid sampling, Management Zone delineation, and Interpolation methods used in Precision Farming.

Precision Technologies and Management Zones

The Congressional Research Service (CRS) defines Precision Agriculture (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” (Congressional Research Service, 2000). These 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 (Powers, 2002). 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.
A technology that has been developed to match inputs with variable field conditions is variable rate technology (VRT) (Powers, 2002). VRT is an all-encompassing term referring to any equipment designed to allow the rate of a farm input to be precisely controlled and varied while the machine is actually in operation. This technology often involves the use of a combination of electronic controllers and variable rate pumps, motors, or valves (Pocknee).

Another important technology used in PA is grid sampling. There are two basic types of grid sampling: grid cell sampling and grid point sampling. Grid cell sampling is a very basic form of zone management. The zones formed are regular, uniform grid cells. Where several neighboring cells return similar soil test values, the zone may consist of those several cells. Essentially, grid cells are zones that do not take field characteristics into account (Pocknee). Grid point sampling is one method for helping determine zone size and position. Where multiple neighboring grid points return a similar soil test value, there can be a reasonable expectation that a homogeneous zone exists around those points and that its spatial extent is being mapped by the sampling design (Pocknee). Advantages of grid sampling are: 1) it is simple and requires little initial field investigation or setup and 2) software exists to facilitate it. Disadvantages of this method are: 1) no consensus on an appropriate grid size (or on how to determine one) 2) a very expensive and labor intensive method.

Management Zones, on the other hand, are currently the most practical way to implement the theory of PA (Kvien; Pocknee). Although the use of Management Zones in today’s farming has grown considerably, some farmers are still cautious of introducing this relatively new practice into their long-established traditional operations.
Furthermore, a producer with a 200 acre farm (in contrast to a producer with a 2,000 acre farm) will have second thoughts on implementing a procedure that requires such a large investment, as these additional costs will likely eliminate (at least for the first couple of years), its potential profits.

Management Zones though are not a new concept. They are as old as farming itself. If they seem familiar, it is probably because of their very ubiquity. There are very few fields in the country which have not, at one stage or another had a zone or section singled out for special attention. Fields themselves are arguably just Management Zones within a single farm. Management Zones possess a deceptive simplicity that has led some in the precision agriculture industry to dismiss them as being "not technical enough" (Kvien). The lack of any simple way to quantify the decision making process and to distill it into computer interpretable algorithms has led others to label it "un-scientific" (Kvien). Its very familiarity and the seemingly arbitrary manner in which it is being applied on "non-precision farming" farms has led others to overlook it simply because they are looking for more "high-tech" non-familiar solutions (Kvien; Pocknee).

"Management Zones are regions of a farm field that have been differentiated from the rest of the field for the purpose of receiving individual management attention" (Kvien; Pocknee). The simplicity of this definition and wide breadth of interpretation is key to the value of this management tool. For those who want a "cook-book" approach to precision agriculture, it is also a source of some confusion. There are no set rules for creating a management zone. The specifics of a particular management zone can only be determined on a site-specific basis and must include all the factors that affect management on a farm. This means that the zones are not solely functions of a field's
physical properties. Management Zones must take into account all relevant input from the socio-political-economic-agro-ecological system that is a modern farming operation (Kvien; Pocknee). It is also very important that these zones be analyzed, evaluated and adjusted over time. They are not static and will change as the management style and capabilities of the farmer change.

**Contemporary Closely Related Studies**

According to Dillon (2002), the economic profitability of PA technologies is a common question for producers considering its adoption. Precision agriculture may or may not be profitable, depending on the crop, inputs and field conditions (e.g., topography, soils, pests and microclimate). To date, the most comprehensive review of PA 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. The most common economic benefits were: cost reductions through savings on inputs, more investments in new technology, and greater accuracy in decision making (better information leading to better decisions was expected to be profitable in the long term) (Lambert and Lowenberg-DeBoer, 2000).

However, the very concept of PA is based on the ability to manage factors of production according to field variability. This in turn requires a need to identify and delineate appropriate Management Zones (Kvien; Pocknee). While there are no set methods for delineating Management Zones, the tools used to do so will depend on the resources and skills available in a given situation. The quality of the resulting zones will depend both on the skills and resources available and the nature of the field being mapped. The tools used on one field may be totally inadequate for another. If there are
insufficient skills or tools available, or if the field is sufficiently complex, the best situation may be not to create Management Zones. Therefore, the identification of the economically optimal Management Zones and including optimal uniform grid size is a complex issue central to the successful implementation of variable rate input application for any given field.

Since one of the main objectives of this research is to delineate Management Zones using yield monitor data, it is imperative to understand first what the concept of yield monitoring entails. Yield monitoring is a way to measure crop output at specific points in a field by using a yield monitor and a global positioning system (GPS) receiver in a combine as the field is harvested. The yield monitor and GPS data are used to create a yield map that indicates the spatial variation in yield within a field (Rains). The primary reason to map yield is to understand what is going on in the field so the producer can make better management decisions and increase profit (Pocknee).

While a yield monitor helps to identify variability within a field, there is another tool, a “profit map”, that is directly related with the decision making process for producers. A profit map can be created using records of field inputs, records of crop yield, and crop sales information (NESPAL). The profit map goes beyond simple yield maps by indicating areas of the field where marginal revenues are greater than or equal to marginal costs.

The first step in creating a profit map is to estimate total revenue, given yield and crop prices. Then, calculate the fixed costs, such as amortized land costs, rentals, irrigation, equipment and variable costs, such as fertilizer, pesticides, energy/fuel, and subtract them from total revenue. The yield map can then be processed into a profit map.
Taking the yield from the map, calculating the profit over the field, and smoothing the data create the preliminary profit map. Smoothing is a method of filtering, interpolating, and extrapolating to smooth raw geo-referenced data into a map. In other words, the net income for a particular field will be higher if the low yielding locations were not planted. Unfortunately, "not planting" an area is not always a feasible option. Many fields have a center pivot irrigation system which requires some management for the pivot to run and would increase the average planted cost per acre to operate the pivot if some land were not in production. A center pivot requires a big capital investment and producers want to get the most return from their investment. Future research will continue to examine equipment costs, land costs and other economic factors that could improve the benefits of precision farming management (NESPAL).

A number of procedures have been used to delineate within-field Management Zones for site-specific management. One approach uses relatively stable soil properties, such as soil electrical conductivity (EC) or landscape features in conjunction with soil-landscape models, to estimate patterns of soil variability. “Topographic attributes and landscape position data have been widely used to map within-field areas of high and low productivity based on water availability” (Fridgen et al. 2000). Slope position and landform are topographic features that have been studied to explain water and crop productivity relationships (water stress) for agricultural soils worldwide. In these studies, footslope positions generally had greater yields than side-slope positions unless ponding (areas with excessive accumulation of water throughout the field) resulted from the poor drainage. Footslope areas are described as the component of the hill slope that forms the inner, gently inclined surface at the base. The surface is dominantly concave in profile.
and is transitional between erosion and deposition of water. Soil EC has also been used to investigate yield variability caused by soil water differences (Fridgen et al. 2000).

“Because of the continuous nature of soils data, classification systems that allow any one observation to belong to exactly one class are often inappropriate. Fuzzy or continuous classification procedures were developed for use in situations where the class boundaries are not sharply defined. In contrast to crisp classification, continuous classification procedures allow individuals to have partial class membership” (i.e. an individual can belong to more than one class) (P.A Burrough et al., 1992). Continuous classification has been widely used for soil classification and delineation of management units (Fridgen et al. 2000).

Unsupervised classification or clustering with the fuzzy $k$-means algorithm (fuzzy $c$-means) is a way to identify naturally occurring clusters in the data. Fuzzy $k$-means is a fuzzy generalization of the $k$-means algorithm described by J.T.Tou and R.C.Gonzalez (1974). The unsupervised classification procedure can be used to delineate two fields into a maximum of eight Management Zones. As the number of zones increased, less pronounced areas (with lower elevations and low EC) and possibly less interpretable features were included.

Fridgen et al, (2000) used the concept of fuzzy $k$-means to delineate within-field Management Zones using soil and field characteristics, such as landscape features. Soil electrical conductivity, elevation and slope, measured in two claypan soil fields were used for the clustering process (Fridgen et al. 2000). Measures of cluster performance and yield data were used to evaluate the “goodness” of the resulting potential Management Zones and to determine the optimal number of zones for a given field. For this study,
Grain yield data were obtained from a combine equipped with a commercial yield sensing system and global positioning system (GPS) receiver. Yield patterns varied considerably from year to year due to differences in climate and crops grown.

Fridgen et al., (2000) concluded that continuous classification has advantages over crisp classification procedures because: 1) partial class memberships are allowed and 2) continuous data are better represented. However, little reduction in within-zone yield variance may suggest either that yield is uniform across the entire field or that important factors contributing to yield variability were not considered during zone delineation. “The appropriate number of zones to use when dividing a field may vary between years and is often dependent on the weather and the crop grown. A greater number of zones are generally required during years with below average precipitation or when water stress occurs during critical development periods. Topographic attributes and soil EC are indicators of plant-available water and are useful in management zone delineation” (Fridgen et al. 2000).

In 1998, research began on a 15-acre field of the Delta Research and Extension Center in Stoneville, MS, to examine the spatial variability of both corn and cotton yields in a rotational system (Sudbrink et al. 2002). The research evaluated the use of yield maps as a resource for determining the correlation between Management Zones across crops over periods of time. For this study, the field was geo-referenced with plots (cells) maintained in the same area in subsequent years. Each cell consisted of four 40-in rows 82 feet in length and arranged as eight tiers with 62 strips. Soil samples were taken after each crop was removed. In examining the yield maps from the different crops, it became obvious that the yields maps were different depending on the crop being grown. The two
corn yield maps were somewhat similar in distribution (plants were symmetrically distributed along the field) but were quite different with respect to actual yields. In contrast, corn yield maps were reasonably different from the cotton yield maps. What had been the lower yielding corn areas were not always the lower yielding areas with respect to cotton. As expected from visual observations, the lower yielding cotton areas at the first harvest were the higher yielding areas at the second harvest. However, even after the two harvests were added together, there were still obvious differences in yields by location within the field.

In summary, the yield maps provided an indication of the high and low yielding areas in a field. However, multiple years will be needed to better identify the reasons for the variability that was evident in the field. This is mainly because most PA concepts, such as yield maps, profit maps and yield monitors, are still being “tested” to measure their potential in an integrated production system.

An example of remote sensing procedures that appears to have a potential application in Cotton Integrated Pest Management (IPM) are vegetation maps that scan large areas of land. Remote sensing techniques have been around for a long time but have had limited application in agriculture. Commercial remote sensing has greatly improved over the last few decades as the quality of digital imagery has improved. “Today, an increasing number of growers are looking towards digital imagery as a tool to enhance their farming operation” (Wells). Coupled with GPS technology and GIS, remote sensing offers potential for improving the economic efficiency of farm management practices.

“This information is extremely valuable in the development and maintenance of area-wide pest management programs, such as boll weevil, *Anthonomus grandis*, 
eradication in cotton” (Summy et al. 1989). Recent research has focused on the use of multispectral remote sensing systems to detect either cotton plant injury from arthropods or areas of extreme vegetative growth that have a high probability of association with pest infestations. This technology, which relies on vegetation images showing crop growth from planting through harvesting, highlight changes as the season progresses and anomalies such as pest infestation, weed patches, soil compaction and watering problems, which may require differential treatment (Wells).

From these georeferenced images, the location of the problem areas as well as the size of the area affected can be determined. This information can help the farmer make informed decisions about the most feasible solution to a wide variety of problems related to crop production. In addition to highlighting these problem areas, images will help monitor the effectiveness of any corrective actions which may be implemented. Fitzgerald et al. (1999) for example, was able to identify early season spider mite, *Tetranychus* spp., injury to cotton in California using images developed with this type of system. Infestations of cotton aphids, *Aphis gossypii* and silver leaf whiteflies, *Bemisia argentifolii*, on leaves covered with a black sooty-mold fungus were also detected using similar remotely sensed data (Summy et al. 1989). Willers et al. (1999) found that remotely sensed images could identify variations in cotton plant development and be used to separate areas within fields during the production season. Using geo-referencing techniques, field maps that defined similar zones of plant development were created. These maps were used to evaluate the distribution of tarnished plant bugs, *Lygus lineolaris*, within cotton fields. These insects were found in specific highly vegetative areas of the fields and not randomly distributed across the entire field. Sudbrink et al.
(2002) also used multispectral images to study within field variation of tarnished plant bugs and established a strong correlation between the occurrence of this insect and areas of plants associated with extreme vegetative growth.

According to Segarra et al. (1989), production agriculture is facing challenges, such as increasing cost of production, shortage of irrigation water, and increased public concern for the impacts of agricultural production on the environment. To succeed in the future world market, producers must come up with high quality products at low prices while employing environmentally friendly practices. Increased uses of environmentally risky fertilizers, pesticides, and other chemicals have contributed to the increases in agriculture’s productivity in recent decades. Therefore, the use of new technology adoption is seen as one key to increasing agriculture’s productivity in the future. Furthermore, as available resources (water, human capital, and land) become more expensive, extensive research in precision agriculture is expected. Thus, the concept of Management Zones has become fundamental to the philosophy of matching inputs to needs and is gaining a significant role in the application of the different technological procedures in crop production.

New developments in technology now provide better tools to vary the rate of agricultural inputs according to plant needs at a very fine scale. Thus, researchers have been trying to identify Management Zones based on the variability in yield limiting factors within a field. The ultimate goal of precision agriculture is to optimize inputs for agronomic, environmental and economic benefits. This has motivated the need to identify Management Zones in fields, which can be delineated, grouped, and managed in a similar fashion (C.W Fraisse et al., 1999).
Very few studies however, have focused on determining the stability of Management Zones. “Stability measures show how well the Management Zones maintain their relative yield ranking from year to year and from crop to crop” (Moore and Wolcott, 2000). In their study, yields were mapped in fields for three consecutive years. Although these yield maps portray yield averages accurately, they do not provide information on the stability of a yield ranking in a particular zone. If the crop yields of a particular zone are within a similar range every year, then the zone has high yield stability. Unstable yields mean that crop yield is unpredictable from one year to the next. Yield stability must then, be relatively high for Management Zones to be useful in profit maximization strategies. Stability of yield was measured two ways: 1) by correlation procedures 2) by discarding rasters (geographically distinct areas of a field) that exceeded a 20 percent coefficient of variation across the three years. Finally, to transform the yield and stability raster data into more distinct and recognizable zones for management and diagnosis, another step is needed, called contouring, similar to contours used in topographic maps. Contouring is an interpolation method used to distinguish between different levels of an attribute (e.g., elevation, fertility, yield).

Moore and Wolcott concluded that defining Management Zones for production fields provides for various applications in a farming operation. One is increased efficiency in application of inputs based on yield monitor data. As an example, fungicide application in certain crops is often recommended based on yield expectation. If yield falls below a certain level, the marginal cost of fungicide may be higher than the marginal revenues from increased yield.
With a better knowledge of yield capacities on field zones, producers could put in strip trials that allow for equal conditions and valid yield comparisons while conducting on-farm research. Mapping yield in production fields is a second application, which paves the way for improved efficiency and management, improved effectiveness in diagnosing yield-limiting factors, and for conducting on-farm research. Spatial analysis is a third application and must be performed on multi-year yield maps to determine if these zones are stable. Combining Management Zones with other mapped parameters and agronomic information will then lead to better management and increased profits.

A different kind of economic approach to zone management is the one introduced by McGuire (2003) in which sub-field zone delineation is considered as optimal for implementation based solely on maximizing profitability. However, for this approach to be successful, the following steps need to be taken: segmentation of research fields, research based on zones, derivation of management information per zone, segmentation of production fields, implementation of management information per zone, and further analysis of financial information.

The first and most significant step in this system is segmenting fields to sub units that contain similar soil and yield potential. McGuire found that this could be achieved through a variety of techniques. One could be as simple as combining digitized soil maps with multi-year yield data. These soil maps define soil types, while the multi-year yield data defines yield potential. A more complex method might include collection of high accuracy elevation data with either survey grade GPS equipment or a laser plane system. This information would be processed in a GIS to produce a model representing water availability. The wetness model coupled with an electroconductivity soil model produces
an output representing soil type and crop productivity.

Once the segmentation information is in place, the next step is to determine what variables can be adapted to a testing procedure across these zones. By placing these plots across the zones, variables can be compared by soil type and yield potential to achieve maximum cost effectiveness. Finally, McGuire concluded that for growers to maximize their returns with PA, they need to know how to collect good data. Once a sufficient level of education is reached, a precision agriculture management system based on sub-field units will probably be the most economically beneficial use of the technology.

A very important contribution to the study of Management Zone delineation using multiple crop yield data was performed by Basnet et al. (2001). This study incorporated a process known as map standardization, through the use of a user-defined membership function, using decile (decimal values) based control points, for the purpose of combining yield maps of various crops and seasons and bringing them to a common numeric range. Once standardized, these yield maps of various crops and seasons can be combined to a single layer using spatial addition and averaging techniques. The combined map layer can then be reclassified into potentially high, medium and low performing areas to correspond to Management Zones requiring low, medium and high attention, respectively. Therefore, the main objective of the study was to process yield data of several crops and seasons to spatially delineate Management Zones for site-specific management.

While the spatial processing of yield data is preconditioned to map standardization and overlay analysis, the fundamental objective of the study was to develop a yield map standardization technique. This study was conducted on a 40.5 ha field near the city of
Jimbour, in southern Queensland, Australia. Site-specific yield data for barley (1998) and sorghum (1999, 2000 and 2001) were collected during the harvest of each crop using an impact plate AgLeader yield-monitor fitted to the grain harvester. Point yield data were collected at 1-second intervals (ranging from 0.5-4 m apart) along the path of the harvester. Collected yield data, stored initially in a disperse point file format, were spatially interpolated to a common 10-meter grid cell using the Kriging interpolation method. Spatial interpolation was necessary to aggregate excessive yield data points and to compensate for any missing data.

Using GIS software, yield values were calculated on a cell-by-cell basis and a map of average yield values was created. This map was then classified into three (low, medium and high) yield performance classes. Classification was based on equal interval method in which each class has an equal range of values or the difference between high and low values is the same for each class (Mitchell 1999). For example, all the cells with cell-values ranging from 0 to 0.33 tons/ha were classified as ‘low’ class. Each class was considered as a separate zone for site-specific management.

From this study, it was established that user-defining a membership function, using decile-based control points, was useful to rescale yield data continuously between 0 and 1. This method of standardization was coherent because the decile calculation produced adequate statistically comprehensible control points (yield points) from within the dataset to use in the user-defined function that was incorporated in this study.

Combining standardized yield data of several crops and seasons (i.e. 1998 to 2001) produced an average yield map. The classification of the average yield map into three classes, based on the standardization method, revealed that the area of low, medium
and high yield performance were 4.2 ha, 24.7 ha, and 11.6 ha respectively. It was also revealed that the edges of the paddock were performing inadequately.

The purpose of the classification was to discriminate the field on the basis of cumulative yield performances and to identify management zones. Hence, each class represented a separate management zone. A class with low yield performance logically required higher management attention as compared to another class with higher yield performance. Thus, low, medium and high classes represented management zones requiring high, medium and low attention, respectively. The delineation of management zones could be based on factors such as soil and field characteristics (Fridgen et al., 2000), digital elevation model (Pilesjo et al., 2000) and yield maps (Stafford et al., 1999).

Considering crop yield as the desirable end product of the plant production process and the level of yield as the cumulative effect of all yield-influencing factors, it seems logical to use yield maps as the basis to delineate management zones.

This study combined yield data of various crops and seasons within a GIS framework to delineate Management Zones. Combining several yield maps and classifying the output into areas of low, medium and high yield performances enabled the identification of Management Zones. Yield map standardization was essential to combine multiple yield data within a GIS framework. In this particular study, a new yield map standardization method that incorporated a number of statistically derived control points in a user-defined membership function was developed.

Overlaying standardized yield maps to identify areas of diverse yield potential was a straightforward process within GIS. The study revealed that most areas performed
moderately and the areas requiring highest management attention were around the boundaries of the investigated field.

Precision Agriculture applies principles of farming according to the field variability, which creates new requirements for estimating and mapping spatial variability of field attributes. Improvement in estimation quality depends, first, on reliable interpolation methods for obtaining yield values and, second, on appropriate application of the methods with respect to data characteristics (Kravchenko and Bullock, 1999).

The interpolation techniques commonly used in agriculture include inverse distance weighting and kriging (Franzen and Peck, 1995; Weiss et al., 1995). Both methods estimate values at unsampled locations based on the measurements from the surrounding locations with certain weights assigned to each of the measurements. Inverse distance weighting is easier to implement, while kriging is more time consuming and cumbersome; however, kriging provides a more accurate description of the data spatial structure, and produces valuable information about estimation error distributions.

In the interpolation process, a grid, comprising of evenly-spaced rows and columns is laid over the raw data. The intersection of a row and column is called a grid point. Various interpolation techniques are used to calculate the value at each grid point. The calculated values are combined to create a grid file, which forms the basis of the yield map. Once the regular grid has been calculated and grid file created, other techniques are used to present the data. For yield mapping the most common means of presentation is a contour map which represents the different yield levels. Reliable methods of data processing and presentation are of equal importance to the issue of the accuracy of data collection. When recording yield data continuously from a yield
monitor, smoothing techniques are used to help interpret and visualize trends within the data. However, data interpolation must be a compromise between smoothing the raw data to indicate trends within the data set and at the same time presenting the main features of the raw data.

Keckler (1995) outlines a number of properties to consider when determining the grid size. Higher grid densities increase the smoothness of the resulting contour lines. However, Keckler states that an increase in the number of grid points not only proportionally increases the interpolation time, but also the drawing time for the contour maps and the size of the grid file. Therefore, grid density is controlled to a degree by the available memory in the computer. Limited memory, very large raw data files, very dense grids, or any combination of these factors can greatly increase interpolation time to the extent that even modern day computers with 200MHz processors require long periods of time to create a grid file from the raw data.

Finally, a major consideration when specifying the interpolation method and parameters that are required to produce a reliable regular grid from irregular spaced data is the density of the original raw data set. A distinct advantage of any yield mapping system is that data is collected automatically on a regular basis, which in turn means that vast amounts of yield information can be recorded very easily with relatively little expense.

**Precision Farming within Theory of the Firm Economic Notion**

Profit maximization is frequently identified as the primary goal of most farmers. To achieve this goal, the farmer must choose a combination of crops as well as mechanization capabilities where the marginal returns are equated to the marginal costs
for all alternative enterprises. Hence, economic concepts of the theory of the firm are particularly useful in guiding farm managers to accomplish this goal. The basic approach behind this research is that while agricultural producers might be achieving a level of “maximum profitability” given their limitations in collecting information, profitability can be improved by them using site-specific cost and return information. Economic principles using the concept of marginality provide useful guidelines for decision making. This concept specifies that more resources should be used as long as the marginal (additional) benefit from the additional resource exceeds its marginal cost.

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 issue is observed at the field level in terms of marginal cost and marginal returns. Farmers still find it difficult to measure marginal cost and marginal returns at the field level. When precision technologies are applied and the field is divided into zones, the profit maximizing output level calculated at the field level will differ from that of each individual zone. Applying the field-level optimal output to each individual zone will result in some zones producing above the profit maximizing output level and some below. Thus, removing zones 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.

A commonly used PA technology, yield monitoring, collects yield information for individual points (grids) throughout a field. When coupled with expense information,
points that do not cover variable costs can be identified. These areas can then be either removed from production or managed under a regime of variable levels of inputs (Variable Rate Technology) to estimate productivity responses for each zone. Further, we can also be able to determine the profit maximizing level of each input to use in that zone. In any case, the specific decision tool to discriminate between areas of production and non-production is called the partial budget. 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.

The theory of the firm notion assumes that companies, or in this case producers, are always trying to maximize their profits. Farmers invest in some sort of technology to increase profits. Their goal is to always earn a positive profit rather than make a loss (a negative profit). A farm’s profit ($\Pi$) is the difference between its revenue, $R$, which are the earnings from a production, and its cost, $C$, which is what it pays for labor, machinery, and other inputs.

The profit depends on the farm’s marginal cost and marginal revenue. A farm’s marginal cost (MC) is the amount by which the farm’s cost changes if it produces one more unit of output: $MC = \Delta C/\Delta q$, where $\Delta C$ is the change in cost when output changes by $\Delta q$. Similarly, a farm’s marginal revenue, MR, is the change in revenue it gets from producing or incorporating a technological change which is translated into one more unit of output: $\Delta R/\Delta q$, where $\Delta R$ is the change in revenue. If a farm that was producing $q$ units of output produces one more unit of output, the extra revenue, $MR(q)$, raises its profit, but the extra cost, $MC(q)$, lowers its profit. Thus, the change in the farm’s profit is,
MR(q) – MC(q). It is also important to keep in mind that a farm should always set its output where: MR(q) = MC(q).

Another important concept to mention within the theory of the firm notion is the break-even analysis. Similar to partial budgeting, break-even analysis calculates the minimum benefit required from an activity to justify making the change. Break-even analysis will be incorporated in this research as a means of demonstrating its usefulness as a farm management tool by establishing a general benchmark for farmers to use in making the least cost strategy decision. 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.
CHAPTER 3
MATERIALS AND METHODS

Project Overview

Throughout this research, the ESRI GIS software package was used to display, modify and manage yield data collected across three crops (Wheat, Cotton and Milo) over a four-year period of time (2000 through 2003). The basic idea behind this case study is that if high and low yielding points along a specific field can be georeferenced (referenced to a specific location in the farm field), analyzed and proven to be consistent, then we can use this procedure to delineate Management Zones to make specific crop management decisions. This procedure will then be used to establish a pest management strategy in cotton production through the implementation of Spatially Variable Insecticide (SVI) applications to compare the profitability of conventional plant protection strategies to precision farming practices by using GIS procedures.

Previous studies, documented in the literature review section, have analyzed numerous ways to define Management Zones based in characteristics such as: soil properties, soil electroconductivity, topography, etc. Thus, it is important to emphasize that although several ways to determine or define Management Zones presently exist, this study is focus only in exploring yield data as a main source of input (insecticide) allocation as well as a profit maximization strategy. Furthermore, another question that could be raised throughout the course of this study is the issue of how can the findings associated with a particular field, be used to analyze another totally different field. The answer to this question is in the actual concept behind precision farming or site specific farming. The fact is that we have to treat each field as a whole different (site specific) area of study with all its positive attributes or limitations.
Description of the Study Area and Data

For the purpose of this project, yield monitors were used to collect spatially referenced yield data from one field (F1) on a single cotton farm (Hardwick farms) in Tensas Parish, Louisiana about 35 miles Southwest of Vicksburg, Mississippi (Figure 3.1).

![Figure 3.1: Satellite Imagery of the Study Area Map in Tensas Parish, LA.](image)

The planted farmland at Hardwick Farms consisted of 77 semi-contiguous fields totaling an approximate of 1038 acres. The region is noted for its fertile alluvial soils and high cotton yields. While there were 77 semi-contiguous fields on the farm, data were not available for all fields. Data was collected for 1 year on 62 fields, 2 years of data were
collected for 10 fields, 3 years of data was collected for 8 fields and 4 years of data was collected for 7 fields. Data was also collected for (cotton F15) on Spatially Variable Insecticide (SVI) prescription applications based on yield data and for (cotton F48, 49) on SVI prescription applications based on remote sensed images of insect populations.

A four year crop rotation was implemented on field (F1): Wheat (2000), Milo (2001), Cotton (2002) and Milo (2003). The purpose of the rotation was to demonstrate the idea that it is possible to identify, in a given field, areas that were consistently high or low yielding for all crops produced on the field (Figure 3.2).

![Crop Rotation](image)

**Figure 3.2**: Crop Rotation for Field (F1) in Tensas Parish, Louisiana.

**GIS Procedure**

Data for an agricultural GIS comes from several sources. Combine-mounted yield monitors collect yield data during harvest. Field boundaries are often digitized from aerial photography, or existing paper maps. Soil sample data are collected and mapped by crop consultants. The internet has quickly become a valuable resource for locating free and commercial providers. Moreover, the farmer using GIS can see how well a specific
portion of his or her field is performing on a map, instead of looking up the average yield for the field in a record book.

The *ESRI ArcView Spatial Analyst* extension was used to display, modify, and manage the spatial data collected in this project. The *ESRI ArcGIS GeoStatistical Analyst* extension was used to analyze the yield data. GIS tools provide us with organized methods of storing this information. It stores the characteristics of in a database, then links these attributes to features that it displays on a map. ArcView stores the information about each feature as a record in a table and organizes the attributes into columns. ArcView then displays the linked features as a theme in a view. This stored information (features and attributes) can then be manipulated, retrieved and analyzed using ArcGIS methods and tools.

**Analyzing Yield Data across Crops over Time**

Comparing yield data from multiple crops over time requires a transformation of the data. In this case, a standard normalization process is used to facilitate the comparison. The normalization process sets the scale of measure to the same basis.

Normalization has value to the farmer because it allows the comparison of different types of data. Comparison of raw yield data from wheat and cotton that were rotated on the same field is somewhat meaningless, but comparison of their normalized yield values is meaningful, even though they are different crop types.

Using a spreadsheet such as Microsoft Excel, normalization takes only a few steps. First the average yield for the entire field is calculated. A new column is added to the spreadsheet to hold the normalized values for each yield point. A normalization formula is then written and applied to all the yield values: *Normalized Yield = (Yield*
point value/Field average yield)*100. The new column is populated with these values. This way, our set of normalized data will always have an average of 100. Each whole unit above or below 100 represents a one-percentage difference from the field’s average yield. The variation and differences within the yield values are maintained, but now the performance of the yield points can be compared between years and crop types. Therefore, by using normalized yields and manipulating these values through the GIS software, comparisons were made across crops for field F1 (Results from this procedure are provided in Figures 3.3 through 3.6).

Figure 3.3: Normalized yield map for Wheat (Bushels/acre), year 2000.
Figure 3.4: Normalized yield map for Milo (Bushels/acre), year 2001.
Figure 3.5: Normalized yield map for Cotton (Seed cotton pounds/acre), year 2002.
Figure 3.6: Normalized yield map for Milo (Bushels/acre), year 2003.
Creating a Yield Grid Map

Yield monitor point files typically are dense and have a great deal of variation between sampling locations. Further, specific sampling points are not consistent from year-to-year or crop-to-crop. Therefore it is necessary to develop yield grid maps to facilitate comparison across crops over time. For this purpose, there are three alternative methods of interpolation: Spline, Inverse Distance Weighted and Kriging. Deciding which method to use depends on the density and variability of the sample points. The two most common point data files a farmer will be using are yield point files and soil sample point files. Because of the high density and great deal of variation present in yield point files, previous studies have proven IDW to be the most appropriate interpolation method to manipulate this type of data. Therefore, the inverse distance weight (IDW) interpolation method was used in creating 10-foot square yield grids. Figures 3.7 through 3.10 display each of the normalized yield grid maps, Figure 3.11 displays the four year overlaid average yield grid map (reclassified into five classes) created to analyze the yield variability within the field over the four-year period.

Inverse Distance Weighted (IDW)

The Inverse Distance Weighted (IDW) interpolation method assumes that each sample point has a local influence that diminishes with distance. It weights the points closer to the processing cell more heavily than those farther away. Either a specified number of points or all of the points within a given radius can be used to determine the value of each output cell.
Figure 3.7: Normalized yield grid map for year 2000
Figure 3.8: Normalized yield grid map for year 2001
Figure 3.9: Normalized yield grid map for year 2002
Figure 3.10: Normalized yield grid map for year 2003
Figure 3.11: Normalized four year yield mean (Reclassified into five categories)
This method (IDW) is appropriate when the variable being mapped decreases in influence with distance from the sampled location. For example, when interpolating a surface of consumer purchasing power for a retail site analysis, the purchasing power of a more distant location will have less influence because people are more likely to shop closer to home. The IDW method estimates grid cell values by averaging the values of sample data points in the vicinity of each cell. The closer a point is to the center of the cell being estimated, the more influence, or weight, it has in the averaging process.

**Power**

With IDW, you can control the significance of known points on the interpolated values based on their distance from the output point. By defining a high power, more emphasis is placed on the nearest points, and the resulting surface will have more detail (be less smooth). Specifying a lower power will give more influence to the points that are further away, resulting in a smoother surface. A power of 2 is most commonly used and is the default. The characteristics of the interpolated surface can also be controlled by limiting the number of input points used for calculating each interpolated point.

**Determining Yield Stability**

Although normalized yield maps accurately reveal yield variations along the field, they do not provide information on the stability of the yield ranking in a particular zone. “Stability measures how well the Management Zones maintain their relative yield ranking from year to year and from crop to crop” (Moore and Wolcott, 2000). Yield stability across crops over time is critical in identifying management zones. If the yield of a particular zone is in a similar yield range every season, then the zone has high yield
stability. Unstable yields mean that crop yield is unpredictable from one year to the next. Yield stability must then, be relatively high for Management Zones to be useful in profit maximization strategies.

Yield stability was measured two ways: by correlation procedures and by coefficients of variation across the seasons (following Moore and Wolcott, 2000).

To determine the level of correlation between yields from one season to another, a correlation coefficient higher than 0.06 is significant at a probability level of 5 percent (Table 3.1 below illustrates the four year correlation coefficients).

Table 3.1 Four year correlation coefficients

<table>
<thead>
<tr>
<th>Year</th>
<th>Year 00-01</th>
<th>Year 01-02</th>
<th>Year 02-03</th>
<th>Year 00-03</th>
<th>Year 00-02</th>
<th>Year 01-03</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correlation Coefficient</td>
<td>0.109393</td>
<td>0.023825</td>
<td>0.09424</td>
<td>0.120866</td>
<td>0.275867</td>
<td>0.287699</td>
</tr>
</tbody>
</table>

The argument behind the significance of such a low correlation coefficient relies on the number of observations, or in this case the number of yield points. Since the number of observations is very large (there were approximately 10,000 yield points) the value for the correlation coefficient can be very low (0.06) and still be significant at a 5% level of probability.

Therefore, the question of which statistical measure should be consider, significance or variance, depends on what one is testing or concerned about. If one wants results from which to make forecasts or predictions, correlations of 0.7 or 0.8 may not be
sufficient, no matter how significant, since there is still much unrelated variance. If one's results are to be a base for policy decisions, only a high percent of variance in common may be acceptable. But if one is interested in uncovering relationships, no matter how small, then significance is of concern.

Thus, according to Table 3.1 it was established that all but one (Year 01-02=0.023825) of the six correlation coefficients were significant. This indicates in a consistent manner that most of the time throughout the four years of study, there was significant spatial correlation between crop yields from one season to another.

Since the normalized yield grid maps and four year overlaid average yield grid map (four year yield mean) were previously constructed, another procedure through which yield stability was measured was by discarding rasters (grid cells).

It was determined (using the four-year average map) that any grid cell with a coefficient of variation higher than 20 percent (0.2) be considered unstable for the process of developing the yield stability map. In Figure 3.12 – left side, grid cells are color coded (The yellow color denotes areas of unstable yields while the dark color indicates above average yields) to depict both relative yield ranking and spatial stability.

Also, for the purpose of transforming the yield and stability raster (grid) data into more distinct and recognizable zones for management and diagnosis, another step is needed called contouring, similar to contours used in topographic maps. Hence, and through the use specific components of the GIS software, contour lines were delineated by connecting interpolated points of similar yield values. These points were further smoothed to provide a better visualization of the field stability zones.
Yield stability data shown as rasters (grid cells) in Figure 3.12 – left, are shown as contours in Figure 3.12 – right. The same color code for the four yield group ranking was used. Through the aid of these figures, we can appreciate that most of the rasters are stable, increasing confidence in using yield zones for making management decisions or diagnosing yield-limiting factors.

Figure 3.12: Contoured Yield Stability Map to create Yield Stability Zones.
Model Development and Data

Louisiana has experienced decreased cotton acreage in recent years. Harvested cotton acreage has decreased from over one million acres in 1995 to just over 500,000 in 2003. Louisiana cotton producers generally experienced poor economic market returns from cotton in 2003. Even with additional income from government programs, many Louisiana producers were unable to show a profit from cotton production in 2003. Continued poor profit potential will likely cause a significant quantity of traditional cotton acres to be planted in alternative crops. It is expected that many traditional cotton acres will be planted to corn (Paxton et al., 2004). Some of this shift may be attributable to available financing; however, most of the shift will be because of the poor profit potential in cotton.

Precision Farming has the potential to improve profitability by increasing yields and lowering input costs for farmers while providing environmental benefits to the society. These benefits are potentially very important in input intensive cotton production.

Because precision farming has not been as widely adopted in cotton production as in other crop production, information about the yield gains and input savings required to pay for a precision farming system would be useful for farmers considering an investment in technology.

To evaluate the per acre cost of investing in precision farming technology for gathering site-specific information and performing SVI applications; ownership costs were calculated for an Ag Leader Technology PF 3000 cotton yield monitor (Ag Leader Technology, 2003) (Table 3.2).
Table 3.2 Cotton Precision Farming System Equipment and Other Costs

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
<th>Purchase Cost ($)</th>
<th>Useful Life (years)</th>
<th>Salvage Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Yield Monitor (4 Row Picker)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monitor/Controller</td>
<td>1</td>
<td>2,295</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>Sensors</td>
<td>1 Kit</td>
<td>3,185</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>GPS Unit</td>
<td>1</td>
<td>2,995</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Flash Card</td>
<td>1</td>
<td>100</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Installation</td>
<td></td>
<td>500</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>9,075</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Computer Hardware / Software</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>iPQs</td>
<td>2</td>
<td>800</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Site-Mate</td>
<td>1</td>
<td>750</td>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td>Desktop Computer &amp; Printer</td>
<td>1</td>
<td>1,300</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>PC Card Reader</td>
<td>1</td>
<td>30</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>GIS Field Mapping Software</td>
<td>1</td>
<td>1,500</td>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>4,380</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Variable rate Application</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Micro-Trak MT-9000</td>
<td>1</td>
<td>2,000</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>Rawson ACCU-RATE (single)</td>
<td>1</td>
<td>3,925</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>Installation</td>
<td></td>
<td>500</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>6,425</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Computer hardware and GIS field mapping software costs were an average for several software vendors. A Rawson variable rate controller and a Micro-Trak Mt-9000 controller make up the equipment set for spatially variable application of insecticide (Rawson Control Systems, Inc., 2003; Micro-Trak Systems, Inc., 2003).

Depreciation and interest rate were calculated using the capital recovery method with a zero salvage value and a real rate of interest of 7% based on historical data (U.S. Department of Agriculture, Economic Research Service, 2001). Data on housing costs like that on taxes and insurance vary widely from farm to farm and state to state. When data are not available, the American Society of Agricultural Engineers (ASAE) recommends percentages of the purchase price of the asset. Thus; taxes, housing and insurance (TIH) (1%, 0.75% and 0.25% respectively) were calculated as 2% of the purchase cost (Commodity Costs and Returns Estimation Handbook, 1998).
The total annual ownership cost of the precision farming system for a farm with one four-row cotton picker was estimated to be $3,994 (Table 3.3). This calculation was based on the Capital Recovery Method considering average values assigned to; years of useful life, a 7% real rate of interest based on historical data, a zero salvage value, and a capital recovery factor. This factor reflects the amount of money required at the end of each year to pay interest on the unrecovered capital at the designated rate and recover the investment within the specified number of years (Boehlje and Eidman, 1984). The annual ownership costs per acre were established at $2.80/acre for the 1,428 acres allocated to cotton production on the farm.

Table 3.3 Cotton Precision Farming System Annual Ownership Costs

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
<th>Capital Recovery Charge</th>
<th>Taxes Insurance Housing</th>
<th>Total Annual Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Yield Monitor (4 Row Picker)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monitor/Controller</td>
<td>1</td>
<td>384</td>
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<tr>
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<td>1 Kit</td>
<td>534</td>
<td>64</td>
<td>597</td>
</tr>
<tr>
<td>GPS Unit</td>
<td>1</td>
<td>731</td>
<td>60</td>
<td>790</td>
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<tr>
<td>Flash Card</td>
<td>1</td>
<td>24</td>
<td>2</td>
<td>26</td>
</tr>
<tr>
<td>Installation</td>
<td></td>
<td>84</td>
<td>10</td>
<td>94</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td>1,757</td>
<td>182</td>
<td>1,938</td>
</tr>
<tr>
<td><strong>Computer Hardware / Software</strong></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>iPAQs</td>
<td>2</td>
<td>305</td>
<td>16</td>
<td>321</td>
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<tr>
<td>Site-Mate</td>
<td>1</td>
<td>71</td>
<td>15</td>
<td>86</td>
</tr>
<tr>
<td>Desktop Computer &amp; Printer</td>
<td>1</td>
<td>241</td>
<td>26</td>
<td>267</td>
</tr>
<tr>
<td>PC Card Reader</td>
<td>1</td>
<td>6</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>GIS Field Mapping Software</td>
<td>1</td>
<td>142</td>
<td>30</td>
<td>172</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td>764</td>
<td>88</td>
<td>852</td>
</tr>
<tr>
<td><strong>Variable rate Application</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Micro-Trak MT-9000</td>
<td>1</td>
<td>335</td>
<td>40</td>
<td>375</td>
</tr>
<tr>
<td>Rawson ACCU-RATE (single)</td>
<td>1</td>
<td>657</td>
<td>79</td>
<td>736</td>
</tr>
<tr>
<td>Installation</td>
<td></td>
<td>84</td>
<td>10</td>
<td>94</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td>1,076</td>
<td>129</td>
<td>1,205</td>
</tr>
<tr>
<td><strong>Total Annual Cost</strong></td>
<td></td>
<td>3,597</td>
<td>398</td>
<td>3,994</td>
</tr>
</tbody>
</table>

The total annual ownership cost of the precision farming system for a farm with one four-row cotton picker was estimated to be $3,994 (Table 3.3). This calculation was based on the Capital Recovery Method considering average values assigned to; years of useful life, a 7% real rate of interest based on historical data, a zero salvage value, and a capital recovery factor. This factor reflects the amount of money required at the end of each year to pay interest on the unrecovered capital at the designated rate and recover the investment within the specified number of years (Boehlje and Eidman, 1984). The annual ownership costs per acre were established at $2.80/acre for the 1,428 acres allocated to cotton production on the farm.
The years of useful life of the equipment were selected on the basis of versatility, ability to be used or mounted with other moving parts or crops, and the estimated wear-out life based on manufacturer literature. It is also important to realize that most of this machinery (hardware and software) is being constantly upgraded and modified because of new technological developments in the industry. Since a large amount of the equipment (beside the software packages) has been allocated for the specific purpose of developing this project, the salvage value, which is an estimate of the remaining market value of the machine at the end of the useful life, is zero.

Depreciation and interest combined represent the amount of money set aside to make the loss in value of the asset and interest on its remaining value. Traditional calculation methods do not provide a large enough sum annually to cover both depreciation of the capital and to pay interest on the unrecovered amount at the specified interest rate in the designated number of years. Thus, the capital recovery method was used to more accurately reflect these costs. The capital recovery method of calculating the annual charge for depreciation and interest is given in equation 3.1.

\[
\text{Annual Capital Recovery Charge:}
\]

\[
\left\{ \frac{\text{Purchase Price} - \text{Salvage Value}}{\text{Capital Recovery Factor}} \right\} + \left\{ \frac{\text{Salvage Value} \times \text{Interest Rate}}{\text{Capital Recovery Factor}} \right\}
\]

\((3.1)\)

The major advantage of the capital recovery approach is that it more accurately estimates the costs involved. The major disadvantage is that we must have access to the appropriate capital recovery factors to use it.
CHAPTER 4
ECONOMIC IMPLICATIONS AND RESULTS

Approach

Historical yield monitor data were used to demonstrate the feasibility of defining Management Zones for (field F1). Given the demonstrated ability to define these zones, yield data from a different location (field F15) were used to delineate Management Zones.

For this purpose, yield monitor data were collected on this field. With the aid of the ESRI ArcGIS Geostatistical Analyst extension, high and low yield point files were identified using a standard deviation procedure and further classified into high and low yielding Management Zones using the IDW interpolation method. Low yielding zones of (F15) were untreated (OFF) and considered SVI areas, while high yielding zones were treated (ON) through a conventional blanket application system. This method comes from the assumption that insects prefer healthier high yielding and less stressed plants as opposed to weakened low yielding stressed plants, and they are not present, or at least not in a representative manner in the low yield portions of the fields.

Furthermore, it is important to clarify that with the intention of providing a more practical scenario for this analysis and to facilitate the economic comparison between conventional and SVI treatments, this study will take into consideration the whole cotton acreage of the farm instead of just one single field. This way, the marginal costs associated with the implementation of site-specific technology will be based on more practical values ($/acre of total cotton farm acreage) instead of trying to establish a relationship based on assumptions that may not be useful to a producer trying to maximize profits by applying these procedures.
Findings from This Analysis

For (Field 15), out of 270 acres, 52 acres were classified as low yielding, through the implementation of a Management Zones system. These 52 low yielding acres were identified throughout the field as SVI Zones, and were left untreated (Figure 4.1). The basic idea behind this procedure was to demonstrate that SVI applications hold the potential for increasing profits by reducing production costs while maintaining acceptable yield levels throughout the field.
Based on the calculations shown in Table 3.3, a cost of $2.80/acre was established to perform SVI applications, from the purchase of the necessary machinery. Thus, the cost of this machinery can be considered as the annual fixed cost per acre of implementing VRT for the specified field. The reason why these costs are considered fixed, is because this machinery is going to be used throughout the field anyway, whether or not the airplane is spraying.

In addition to the machinery, insecticide costs (Table 4.1), are considered an annual variable cost. The cost of the insecticide combination for field 15 is $26.87/acre.

<table>
<thead>
<tr>
<th>App #</th>
<th>Treated Acres</th>
<th>Untreated Acres</th>
<th>Product used</th>
<th>$/acre</th>
</tr>
</thead>
<tbody>
<tr>
<td>App # 1</td>
<td>218</td>
<td>52</td>
<td>Baythroid + Orthene</td>
<td>2.58 + 4.83</td>
</tr>
<tr>
<td>App # 2</td>
<td>218</td>
<td>52</td>
<td>Orthene</td>
<td>4.83</td>
</tr>
<tr>
<td>App # 3</td>
<td>218</td>
<td>52</td>
<td>Bidrin</td>
<td>4.90</td>
</tr>
<tr>
<td>App # 4</td>
<td>218</td>
<td>52</td>
<td>Bidrin</td>
<td>4.90</td>
</tr>
<tr>
<td>App # 5</td>
<td>218</td>
<td>52</td>
<td>Orthene</td>
<td>4.83</td>
</tr>
</tbody>
</table>

To evaluate the reduction in costs on the SVI areas; the untreated acres of the field (52 acres) are multiplied times the cost of the insecticide ($26.87/acre); \([(52 \times 26.87) = \$1,397]\). Therefore, savings in the amount of $1,397 are accomplished through SVI applications out of 52 untreated acres.

Furthermore, to visualize the amount of savings on a per acre basis for the entire field 15, the amount of savings ($1,397) is divided by the total acreage of this field (270
acres); \((1,397 \div 270) = 5.17\). Therefore, savings in the amount of $5.17/acre are achieved through the implementation of SVI applications.

Although there appear to be annual savings of $5.17/acre from implementing VRT on F15, we must take into account an annual fixed cost of $2.80/acre from purchasing the necessary equipment. Thus, fixed costs must be subtracted from the input (insecticide) savings to have a clear picture of the actual cost reduction on this field; \[\left(\$5.17 - \$2.80\right) = \$2.37\]. Therefore, findings from this analysis suggest an annual reduction in costs of $2.37/acre or $640 for the entire field, through the utilization of site-specific management and VRT.

**Break-Even Acreage Analysis**

Before engaging in precision agriculture (PA) it is important to determine the least cost strategy of obtaining the technology. High equipment cost has resulted in the adoption of PA mainly on large farms, in part due to the high fixed cost. Spreading this cost over a larger acreage may improve profitability. Therefore, it is important to realize what size of farm is required to justify the investment in the technology.

To minimize the cost of switching from traditional farming to PA, the producer needs to know when to choose either of the options. A break-even analysis enables the producer to know at what point it is no longer profitable to purchase the PA equipment.

Break-even analysis permits one to develop a general benchmark for a more robust, broadly applicable, tool. Specifically, a producer must possess sufficient acreage to reduce the average fixed cost of equipment ownership to justify its purchase. Custom hiring would be more cost effective for a farmer with a small farm size in terms of acreage. But, at some point, a farmer with enough land would be expected to benefit
more by owning the equipment than through custom hire. Given the fact that this minimum cost decision is largely a function of farm size, solving for the break-even acreage point of indifference between the two alternatives provides a benchmark for farmers to use in making a least cost strategy decision.

**Analysis Framework**

As shown previously in the results section of the analysis, savings in the amount of $5.17 per acre were established from spraying less insecticide on field (F15) through SVI applications out of 52 untreated acres. Additional costs (fixed costs) on the amount of $2.80 per acre were also calculated through the capital recovery method from the purchase of the necessary equipment. Thus, net savings in the amount of $2.37 per acre were established through the utilization of site-specific management and VRT.

Therefore, and to justify the purchase of the necessary technology, the total annual fixed cost ($3994) is divided by the amount of savings in insecticide ($5.17 per acre) to determine the break-even acreage required to cover the total annual ownership cost of the precision farming system.

\[
\frac{\$3,994 \text{ annual fixed cost}}{\$5.17 \text{ insecticide savings}} = 772.5 \text{ acres}
\]

This relation between the annual fixed cost and the insecticide savings suggests that the break-even acreage required to cover the necessary investment in technology for this farm is about 772.5 acres.

Notice that the budgeting of the specific costs associated to this technology were considered to be independent on whether the field was established under continuous cotton production or in rotation with other crops.
However, it is still important to recognize that fixed costs were the most critical element of the break-even analysis. A reduction in equipment cost decreases the break-even acreage, thereby, making the technology available to a wider audience of farmers. Purchase of the equipment may provide additional advantages such as better management and control of data and data generation. Ownership also enables the farmer to gain experience with PA equipment and practices, as opposed to reliance on the PA service provider or custom operator. Finally, purchase of the technology may facilitate its use over more operations such as variable-rate seeding, thereby spreading the fixed cost over more activities and further reducing per acre total ownership costs.
CHAPTER 5
SUMMARY, CONCLUSIONS AND FUTURE RESEARCH

Summary

The idea that “by maximizing profits on a sub-field level, profit for the whole field is improved” has motivated both, people in the research area as well as producers to come up with alternative ways of identifying and utilizing sub-regions of the field as experimental stations. Combining state of the art technology, several years of historical data and experience with a twist of risk, precision agriculture (PA) or also called site specific management and its various components such as: Geographical Information Systems (GIS), Management Zones and Variable Rate Technology (VRT) had opened a gateway to a whole new dimension of possibilities in the agricultural sector.

The need to evaluate the economic implications of using management zones in cotton production arises because of the extensive cotton acreage that populates the state of Louisiana and thus, the need for better and more efficient farming practices that can retrieve a good portion of the investment that public and private sectors have designated for the purposes of increasing productivity as well as minimizing input costs.

The general objective of this study is to determine a consistency in delineating Management Zones within a multi-crop production system using yield monitor data and through this, evaluate the economic feasibility of performing pest management strategies in cotton through the use of spatially variable insecticide applications (SVI) to increase
profit potential for the producer by maintaining average yields and reducing production costs.

Specific objectives of this study were:

1. To delineate Management Zones using yield monitor data.
2. To determine the consistency and reliability among Management Zones across crops over time.
3. To assess the potential impact on farm profits of comparing conventional plant protection strategies to strategies based on precision farming technologies in cotton production.

This study used yield monitor data from one field (F1) on a single cotton farm (Hardwick Farms) in Tensas Parish, Louisiana about 35 miles Southwest of Vicksburg, Mississippi. The planted farmland at Hardwick Farms consisted of 77 semi-contiguous fields totaling an approximate of 1038 acres. A four year crop rotation was implemented on field (F1) starting with; Wheat (2000), Milo (2001), Cotton (2002) and Milo (2003). The purpose of the rotation was to demonstrate that it is possible to identify, in a given field, areas that were consistently high or low yielding for all crops produced on the field.

Chapter 2 provided a literature review relating to previous studies on the economics of precision agriculture and explores the numerous areas of research involved in its development. Some studies described include: Variable rate technology with respect to insect pest management in Cotton, Grid sampling, Management Zone delineation and Interpolation methods used in Precision Farming. Also, a section describing the economic
theory behind the concepts of marginality, profitability, ownership costs, partial budgeting and variability of inputs was incorporated in the form of theory of the firm.

Chapter 3 presented the materials and methods dealing with the procedures incorporated to define and analyze Management Zones as well as the methodology and data used to calculate the different costs associated with the implementation and evaluation of the technology.

The *ESRI Geographical Information System (GIS) ArcView Spatial Analyst* extension was used to display, modify, and manage the spatial data collected in this project. The *ESRI ArcGIS GeoStatistical Analyst* extension was used to analyze the yield data. ArcView stores the information about each feature as a record in a table and organizes the attributes into columns. ArcView then displays the linked features as a theme in a view. This stored information (features and attributes) can then be manipulated, retrieved and analyzed using ArcGIS methods and tools.

Comparing yield data from multiple crops over time requires a transformation of the data. In this case, a standard normalization process was used to facilitate the comparison. The normalization process sets the scale of measure to the same basis. By using normalized yields and manipulating these values through the GIS software, comparisons were made across crops for field F1.

The two most common point data files a farmer will be using are yield point files and soil sample point files. Because of the high density and large amount of variation present in yield point files, previous studies have shown IDW to be the most appropriate interpolation method to manipulate this type of data. Therefore, the inverse distance weight (IDW) interpolation method was used in creating 10-foot square yield grids. IDW
assumes that each sample point has a local influence that diminishes with distance. It weights the points closer to the processing cell more heavily than those farther away. Either a specified number of points or all of the points within a given radius can be used to determine the value of each output cell.

Although normalized yield maps accurately reveal yield variations along the field, they do not provide information on the stability of the yield ranking in a particular zone. Yield stability across crops over time is critical in identifying management zones. If the yield of a particular zone is in a similar yield range every season, then the zone has high yield stability. Unstable yields mean that crop yield is unpredictable from one year to the next. Yield stability must then, be relatively high for Management Zones to be useful in profit maximization strategies.

Chapter 4 presented the economic implications and results obtained from this study. For Field (F15), out of 270 acres, 52 acres were classified as low yielding, through the implementation of a Management Zones system. These 52 low yielding acres were identified throughout the field as SVI Zones, and were left untreated. A cost of $2.80/acre was established to perform SVI applications, from the purchase of the necessary machinery. In addition to the machinery, there was the insecticide cost. The cost of the insecticide combination for field (F15) was $26.87/acre.

To evaluate the reduction in costs on the SVI areas; the untreated acres of the field (52 acres) were multiplied times the cost of the insecticide ($26.87/acre); [(52 * 26.87) = $1397]. Therefore, savings in the amount of $1397 were accomplished through SVI applications out of 52 untreated acres.
To visualize the amount of savings on a per acre basis for the entire field 15, the amount of savings ($1397) was divided by the total acreage of this field (270 acres); \[(1397 \div 270) = 5.17\]. Therefore, savings in the amount of $5.17/acre were achieved through the implementation of SVI applications.

Fixed costs were finally subtracted from the input (insecticide) savings to have a clear picture of the actual cost reduction on this field; \[(5.17 – 2.80) = 2.37\]. Therefore, findings from this analysis suggested an annual reduction in costs of $2.37/acre or $640 for the entire field, through the utilization of site-specific management and VRT.

A break-even acreage analysis was introduced in the results section of the study as a mean of establishing a general benchmark for farmers to use in making a least cost strategy decision. Therefore, and to justify the purchase of the necessary technology, the total annual fixed cost ($3994) was divided by the amount of savings in insecticide ($5.17 per acre) to determine the break-even acreage required to cover the total annual ownership cost of the precision farming system. This relation between the annual fixed cost and the insecticide savings suggests that the break-even acreage required to cover the necessary investment in technology for this farm was about 772.5 acres.

Conclusions

This thesis has examined the use of precision agriculture (PA) data, particularly yield monitor data, for agricultural decision making. Results from four years of data indicate that it is possible to identify, in a given field, areas that were consistently high or low yielding for all crops produced on the field. These areas were identified under a management regime that applied production inputs uniformly across the whole field.
Undoubtedly, the primary concern about precision agriculture is profitability. Studies that have examined this issue have generally shown positive results, but profitability is very dependant upon crop, with many crops currently having little to no conclusive data.

It was interesting to note that most of the literature revised throughout the development of this paper portrays precision agriculture and all of its tools as a means of increasing profitability for its adopters, when in reality perhaps the primary question that still surrounds this concepts is “does it pay?” In my opinion, this question is yet difficult to answer because there are: several approaches to economic analyses, costs that are either overlooked or just don’t seem to fit into a specific category and benefits with a somehow subjective value.

Producers need decision tools that are applicable across broad and varying conditions. Although the conditions surrounding the determination of the general profitability of PA are individual and farm dependent, the costs of engaging in PA are less likely to differ from producer to producer. Furthermore, cost minimization is essential for profit maximization. Therefore, for producers who decide to engage in PA, it becomes necessary to investigate the least-cost strategy of adopting the technology.

Reduction of production costs is known to be the leading reason for early adopters to engage in PA. The expectation in most cases is that adopting PA technology will lead to a reduction in the quantity of input used while increasing yield. However, we should keep in mind that while some inputs (e.g. fertilizer or pesticides) may be reduced with PA, others (e.g. equipment or machinery) may increase. Thus, the additional cost incurred from switching from traditional "field-level" to "precision agriculture" has
become critical because it balances against the reduction of other inputs and increased yield. While some may consider the expense of PA equipment ownership to be a constraint to its adoption, they may fail to recognize that custom hiring may be a practical alternative. Therefore, the additional cost of engaging in PA can either appear in the form of an investment in PA equipment, or as a custom-hire rate.

Throughout this research, the concept of Management Zones was evaluated and further proven to be consistent across crops over time. The process of defining a Management Zone could be seen as complex in terms of the data collection and manipulation. Thus, GIS is becoming a more user friendly tool every day and soon it will be as simple as a spreadsheet.

Spatially Variable Insecticide applications (SVI) were demonstrated to be profitable. It is important to mention that the use of precision agriculture has gained popularity in Louisiana over the past decade, and while the use of PA technologies will not always give Louisiana farmers a prescription of the decisions they need to make, it will provide them with the tools from which they can collect and analyze information from which their decisions are based.

Finally, we should keep in mind that regardless of what new technologies become available in the near future, the basis for accurate and profitable application of crops inputs uniform or variable, will continue to require a clear understanding of the agronomic factors that directly affect crop growth and yield within each growing season.

**Future Research**

Further studies in this area might be designed to evaluate the application of a management zone approach in terms of low, medium and high productivity zone
delineation. Information obtained from these studies can be used to estimate production response surfaces for each of the zones. These response surfaces can then be used to determine the profit maximizing level of each input to use in that zone. Once these levels are identified, Variable Rate Technology can be incorporated to apply predetermined volumes of inputs to meet the requirements of each particular zone.

For site-specific management, future research concerning the proper management operation or agrichemical input(s) to be employed is needed to determine the procedure of how to divide the field into more reliable management zones. With some management operations, grid-soil sampling and mapping of nutrient may be the most appropriate option. Other research applications may include sampling by differences in soil type or elevation. However management zones are determined, each zone should represent a unique combination of potential yield-limiting factors for which we can improve the site specific management prescription.

Nevertheless, the most durable contribution that researchers, farmers and agribusiness can make in this area is the development of management skills and data bases. Hardware and software are sure to change, but site specific data bases and the capacity to use precision management tools profitably will provide a long run competitive advantage.
REFERENCES


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VITA

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In 2002, he was awarded an assistantship by the department of Agricultural Economics & Agribusiness of Louisiana State University to pursue graduate studies in agricultural economics at this University. He is currently a candidate for the Master of Science degree in agricultural economics from Louisiana State University in December, 2004.