Introducing Geographic Information Systems to Grass Seed Growers in the Willamette Valley of Oregon

by
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AN ABSTRACT OF THE THESIS OF

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Oregon is the number one producer of cool-season grass seed in the United States. The center of the grass seed industry of Oregon is located in the Willamette Valley, where about 470,000 acres of seed are grown. Innovative grass seed growers of the area are beginning to implement precision agriculture GIS and GPS technologies on their farms. Fertilizer and chemical companies provide precision agriculture consulting services, including soil nutrient and yield spatial field mapping, for growers. To help growers learn how to work with their spatial field data, a set of GIS lessons were created using ESRI's ArcGIS 9.0. The lessons teach growers how to use GIS for managing, analyzing, and interpreting their site-specific field information. They were introduced to interested grass seed growers through a series of three workshop meetings in January and February 2005. During the meetings, participants completed evaluations to indicate their knowledge and skill of GIS and GPS before and after each meeting. From the evaluations, growers indicated they were interested

in using GIS for investigating correlations between yield and soil nutrients and for creating prescription application maps. Therefore methods for investigating correlations and creating prescription maps were devised using both Microsoft Excel and ArcGIS 9.0. Finally, a specific task-based comparison of four different precision agriculture GIS software packages to ArcGIS 9.0 was completed to provide interested growers with information needed when evaluating software options available to them.

Master of Science thesis of Keldah E. Hedstrom presented on June 6, 2005

APPROVED:

Major Professor, representing Geography

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Dean of the Graduate School

I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Keldah E. Hedstrom, Author

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This research is dedicated to

my family

and to the loving memory of

my father

Olaf Robert Hedstrom.

Without their unconditional love

and support this thesis would

not have been possible.

Thank you.

Introducing Geographic Information Systems to Grass Seed Growers in the Willamette Valley of Oregon

1. Introduction

1.1 Overview

The Willamette Valley of Oregon is known as "The Grass Seed Capital of the World," with the 2004 farm gate value of grass seed exceeding $300 million (Oregon State University (OSU) Extension Service 2005). Approximately 470,000 acres were devoted to grass seed production in 2004. The Willamette Valley produces two thirds of all cool season grasses in the United States (Edminster 2004). The seed is used for lawns and pastures in many areas of the United States and the world. The primary species grown are perennial ryegrass and tall fescue. Much of the straw left over after seed harvest is baled and used as livestock feed both in Oregon and for export to Japan, Taiwan, and Korea (Oregon Seed Council). Farms engaged in seed production range in size from 200 to 5,000 acres, with an average size of about 700 acres, and most are family farms (Oregon Seed Council).

Some progressive grass seed growers in the area have started to use the technologies of precision agriculture on their farms. With precision agriculture, growers attempt to manage for spatial variability within a field by dividing a field into different zones where different rates of inputs are applied as appropriate. Precision agriculture has the potential to improve operations by no longer managing fields as homogeneous units (Morgan and Ess 1997). Precision agriculture uses computers and other technologies to aid in making decisions about where and when to apply crop inputs, which may increase farm profits (Roberts et al. 2002).

Global positioning systems (GPS) and geographic information systems (GIS) technologies provide the foundation of precision agriculture applications to map the spatial variability that exists across a field (e.g., Swinton and Lowenberg-DeBoer 2001). GPS utilizes a system of satellites to pinpoint a location on Earth, while GIS is a computer system used for the mapping and spatial analysis of earth features. Both GPS and GIS technologies can be integrated to map and analyze yield and other spatial data such as results from soil nutrient tests sampled on a grid across a field.

Precision agriculture creates the potential for harvesting the same yields with the same inputs but redistributed within the field, harvesting the same yields with reduced inputs, or harvesting greater yields with reduced inputs (Morgan and Ess 1997). It also has the potential for beneficial effects on the environment. For example, using site-specific crop management to increase production in a field while lowering the amount of inputs used can reduce polluting residuals of nitrogen and other fertilizers into the environment (Khanna 2001).

In the Willamette Valley, the most widely used application in precision agriculture is the mapping of soil nutrients within a field for variable rate application of fertilizer or lime. Growers can make use of their investment in the collection of field site-specific information through the implementation of variable rate technology (VRT) (Morgan and Ess 1997). With VRT, a grower can make site-specific variable-rate applications of inputs instead of uniform applications of inputs over a field.

The majority of the research in precision agriculture has been performed in the Midwest on corn and soybean crops (Lambert and Lowenberg-DeBoer 2000;

Daberkow and McBride 1998; Griffin et al. 2004). Only a handful of studies have been performed in the Pacific Northwest, including those by Righetti and Halbleib (2000) and Yang et al. (1998), but none of these were in grass seed.

Grass seed growers in the Willamette Valley are beginning to use yield monitors on their combines. A yield monitor takes GPS readings of location while simultaneously measuring the amount of seed coming into the combine as it moves. With these data, maps can be created in GIS indicating how the yield varies in different parts of the field.

Many Willamette Valley growers interested in precision agriculture applications utilize the services of local fertilizer and chemical companies who have the necessary precision application equipment and who do custom applications, although a few growers have their own equipment. The fertilizer and chemical companies also provide precision agriculture consulting services for a per acre fee. These services include making soil nutrient maps based on grid-sampled soil tests, making yield maps from the grower's combine yield monitor data, and providing advice to growers on management decisions. Usually the consulting company keeps the grower's spatial data on a computer and the grower receives paper copies of the field maps. The grower eventually ends up with notebooks full of paper maps (Figure 1.1), and all this information can become overwhelming.

Photo By Susan Aldrich-Markham

Figure 1.1. A grower examining his soil nutrient maps.

Spatial information, while expensive to gather and maintain, is still not valuable to growers unless they can use it to make farm management decisions. Growers participating in this research have indicated they would like to use their spatial field information to look for insights into relationships between yield and other variables that are not obvious from field observation. They want to use spatial information to help them decide whether certain management practices will improve crop yields. For example, a grower might be able to increase yields by applying fertilizer at higher rates where higher yields are possible or he might save money by reducing rates where yield will always be limited by other factors such as soil type.

Participating growers have also indicated a need to be able to view one or more maps of a field simultaneously so they can see if and where various field maps align. Being able to view and analyze field data on their own computers would allow growers to manipulate their data whenever they want without being limited to the amount of time the precision agriculture consultant can spend with them. If they had their data on their own computers, they could change the way their maps look as well as try out various "what if" management scenarios. Participating growers indicated that in an ideal situation they would be able to store and handle all of their precision agriculture data in a single GIS program. They might have different types of electronic field data, and if it requires different programs to view the data they can't view it simultaneously.

Currently, Willamette Valley growers have received little, if any, financial return from precision agriculture applications; they have just received a lot of yield and soil nutrient spatial information about their fields. It is yet to be proven by research if precision agriculture technologies are economically beneficial, as the components of farm decisions are very complicated (Atherton et al. 1999). However, if crop yield variability occurs within a specific farm field, precision agriculture technologies may be able to help in understanding why, as well as providing possibilities for variability management.

Many barriers to precision agriculture adoption exist, so these farming methods are not automatically adopted and implemented by grass seed growers. Economics, i.e. costs of equipment, data, and time, have been found to be the primary reason for slow adoption rates of precision agriculture technologies (Barao 1992; Arnholt et al. 2001; Roberts et al. 2002; Khanna et al. 1999; Swinton and Lowenberg-DeBoer 2001; Daberkow and McBride 1998; Daberkow and McBride 2000). Other barriers to adoption include growers' lack of time to spend in learning the technologies, the difficult learning curve of the technologies, and the lack of educational materials for growers to use in learning about the technologies (Khanna 2001; Khanna et al. 1999; Daberkow and McBride 2001; Wiebold et al. 1999).

Another precision agriculture technology adoption barrier is the lack of grower access to computer software and data analysis training (Wiebold et al. 1999). A few midwestern educational institutions, such as the University of Nebraska (http://precisionagriculture.unl.edu/education.htm), offer precision agriculture technology training. However, there are few, if any, low cost opportunities in Oregon for grower training, especially if the grower has not already purchased the technology. A unique aspect of this thesis is that this work is the first to provide low-cost GIS training specifically designed to address what grass seed growers want to do with precision agriculture GIS and GPS technologies.

1.2 Objectives

The goal of this research was to provide Willamette Valley grass seed growers with a low-cost educational training opportunity in GIS mapping and analysis. In this research, GIS was presented as a potential tool that growers can use in choosing management practices that can increase profits by increasing yields or reducing input costs. Three specific research questions were created to address this goal: **1) Can hands-on GIS training and educational materials be provided to help grass seed growers learn how to manage their precision agriculture information in ESRI's ArcGIS 9.0? 2) Can simple analysis methods in ArcGIS 9.0 be developed to help growers interpret their spatial field information? 3) How does having the direct**

input of growers aid in the development of educational modules or remove impediments to effectively learning GIS for use on their own farms?

The overall goal and questions of this research were addressed through the following six objectives. The use of input from grass seed growers on what they thought needed to be accomplished was a key feature of this research (e.g. objectives 4-6 were formulated after receiving recommendations from participating growers in objective 3). The desire to provide practical and useful GIS tools for growers drove this work from the beginning.

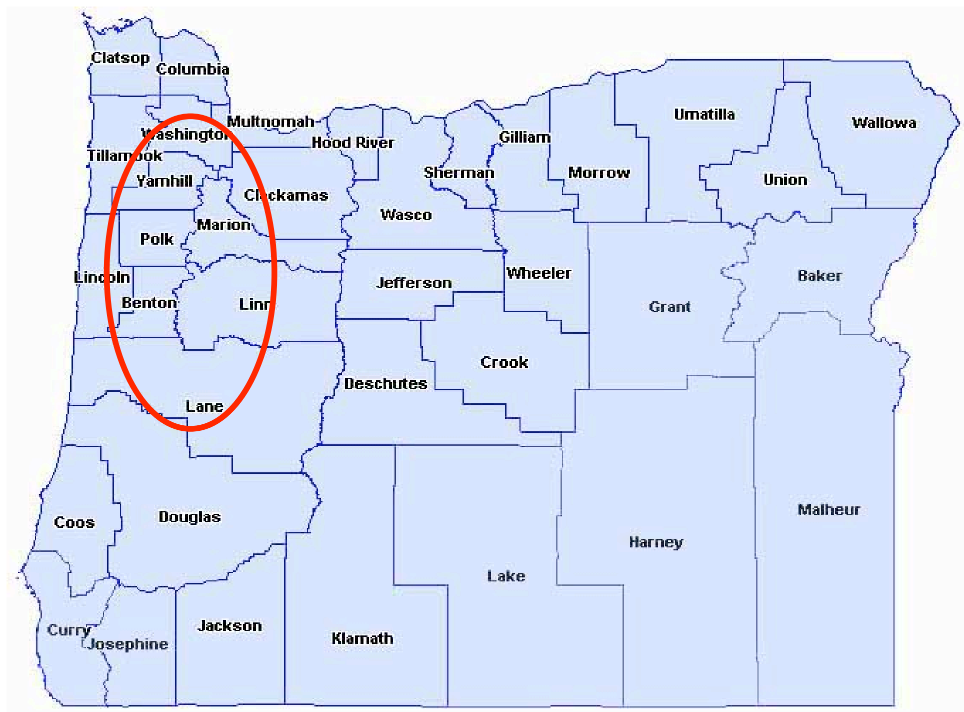
1. Develop a beginning level training curriculum in ArcGIS 9.0 that will make GIS quick and easy to learn, and that focuses on the skills needed to do GIS tasks specific to grass seed production.
2. Present the curriculum, in collaboration with OSU Extension Agent Susan Aldrich-Markham, to a pilot group of grass seed growers from the Willamette Valley in a series of workshops.
3. Evaluate the usefulness of this ArcGIS 9.0 training to growers and gather suggestions from them on what other skills in GIS growers would want to learn.
4. Develop methods in ArcGIS 9.0 for correlating soil nutrients and seed yield using data from three fields in Polk and Linn counties, Oregon, in order to help growers determine whether soil nutrients are limiting the yield in a field.

5. Develop methods in ArcGIS 9.0 for making prescription application maps for fertilizers and plant growth regulator (PGR) chemicals using data from six fields in Polk and Linn counties, in order to help growers make the most cost-effective use of these inputs.
6. Compare five precision agriculture GIS software packages to ArcGIS 9.0 to determine which GIS software is the easiest to use while still providing analysis power for yield mapping, correlations, and prescription mapping. This information can be used by growers to become familiar with available precision agriculture GIS software packages as well as for use in selecting a GIS software program for their operations.

Within this research, growers were presented with skills needed to work with data collected by private fertilizer and chemical companies to expand precision agriculture operations on their farms. The materials produced in this study, including workshop presentations and learning curriculum, will be made available from the OSU Extension Service for interested Willamette Valley grass seed growers.

1.3 Study Area

The Willamette Valley of Oregon is the most diversified agricultural area in the state. The climate is temperate with a long growing season. Winters are wet with 30 to 60 inches of rain a year, while summers are dry with low levels of precipitation (Taylor and Hatton 1999). In addition to grass seed, agricultural crops include hay, grain, clover seed, hazelnuts, apples, pears, cherries, hops, onions, mint, and numerous vegetable crops. Growers participating in this project own farms in Polk, Yamhill, Linn, and Benton counties (Figure 1.2).



Willamette Valley Counties:
Washington, Yamhill, Marion, Clackamas, Polk, Benton, Linn, Lane

Figure 1.2. Counties of the Willamette Valley, Oregon (Map Pro Inc. 2003).

Data from six grass seed fields provided by a key cooperating grower were used in this research. The grower is a frequent cooperator with OSU Extension and was one of the first growers in the Willamette Valley to use precision agriculture technologies on his farm. He was selected because he had extensive yield and soil nutrient data for his fields and was willing to let his data be used as part of the curriculum for training other growers. The fields were located in both Polk and Linn counties (Figure 1.3).

Figure 1.3. Aerial photo of Fields 1 – 6 used in this research.

According to the Oregon Department of Agriculture's publication *Oregon Agriculture Facts and Figures*, in 2004 Linn County ranked sixth among the counties, grossing over $190 million in agricultural sales, while Polk County ranked tenth, grossing over $119 million. In 2004, Linn County reported approximately 193,000 acres of grass seed production while in Polk County reported approximately 59,000 acres (OSU Extension Economic Information Office 2004). Perennial ryegrass and tall fescue are the primary species grown in Linn and Polk counties.

2. Introducing GIS to Grass Seed Growers: Lessons, Workshops, and Evaluations

2.1 Overview and Methods

2.1.1 Lessons

The first step in the study was the identification, by Susan Aldrich-Markham, of a key cooperating grower with interest in using GIS technology to aid in grass seed crop production. Initial discussions were held with this grower to determine what GIS tasks he and other growers would be interested in learning to do on their own. The discussions with the cooperating grower were critical to this project as, "There is no better source from which to learn about the needs of technology users than the users themselves," (Wiebold et al. 1999).

In order to obtain additional insight into what other tasks growers would like to accomplish with GIS technology, a number of discussions were held with staff of agencies involved with the grass seed industry of the Willamette Valley. Agencies involved with this project were providers of a large part of the spatial data being utilized by local growers and included the OSU Extension Service, Polk and Yamhill counties Natural Resource Conservation Service (NRCS), Farm Service Agency (FSA), and the Polk County Soil and Water Conservation District (SWCD). The NRCS, FSA, and SWCD have moved to a GIS – based system, which can potentially increase grower awareness of precision agriculture benefits (Griffin et al. 2004).

During these discussions, information about spatial data needs and mapping outcomes that are important to growers from a production and conservation standpoint were exchanged. It was determined that growers are interested in incorporating the following data into a farm GIS:

- GPS: field boundaries, drain tile outlines, building outlines, etc.
- FSA county aerial photos and imagery
- NRCS soil type maps
- Yield monitor data (for creating yield maps)
- Soil nutrient sample data (for creating soil nutrient maps)
- Veris Cation Exchange Capacity (CEC) maps (for creating more detailed soil texture maps)
- Topographic data (for creating elevation maps)
- County map layers: roads, rivers, township and range, etc.

The second step of the project was to create a set of GIS education lessons. According to Unwin (1997), successful GIS lessons are designed around resource availability and individual student needs and knowledge. In this project, these suggestions were followed, as the GIS lessons were created to utilize available GIS software resources and to meet the needs of the grass seed growers. The GIS needs of grass seed growers were determined through meetings with prospective growers'. The lessons were tailored to focus only on those tasks of interest to growers and to be short enough to fit the amount of time growers would be willing to spend learning the technology.

The GIS lessons were designed to help growers visualize grass seed yield variation and to compare yield maps to field phenomena for a specific field. Within the lessons, specific GIS mapping and geostatistical analyses methods were compiled and outlined. The lessons may become an OSU Extension publication that could be used by Extension agents to teach similar workshops providing growers with information about precision agriculture technologies.

The lessons were created using various public spatial data sets that were collected from the previously mentioned agencies. Data used in the lessons include: Polk, Yamhill, Linn, and Benton counties soils, aerial imagery, rivers, anadromous fish (ocean fish that spawn in freshwater streams) streams, roads, individual farm field boundaries, township, range, and section county data. Data provided by the cooperating grower included elevation, yield, and soil nutrient data from one specific field located in Polk County. For a list and detailed description of the data used in each lesson, see Appendix A.

Following the methods used in Berry (2002), after determining the appropriate GIS tasks for grass seed growers, written materials in the form of seven task-based lessons were created. ESRI's ArcGIS 9.0 was the GIS software chosen because: 1) it could potentially accomplish all grower desired GIS tasks; 2) it can work with multiple spatial data formats; 3) it is easier for growers to learn one GIS program that does everything than to have to learn several simpler programs; 4) OSU has a site license so that the software could be used at no cost and the growers could get six-month free trial licenses, and 5) the company that makes this software is not likely to go out of business (a large frustration for growers is the use of software made by companies that quickly go out of business or stop supporting their products). ArcGIS 9.0 was therefore used for all data processing.

The lessons consisted of step-by-step procedures for using ArcGIS 9.0 functions that describe how to accomplish tasks designed specifically to meet grass seed growers' needs. In the lessons, growers learned how to use ArcMap and ArcCatalog, which are two of the core applications in ArcGIS 9.0.

The focus of the lessons was the creation of the yield map, as yield is what ultimately determines profit or loss for a farm. Yield mapping is one of the most important tools of farm management information systems, as it can provide the basis for crop management adjustments such as fertilizer prescriptions (Righetti and Halbleib, 2000; and Zhang and Han 2002). After accomplishing the task of creating a yield map, a grower can then focus on determining possible causes for poor yield producing areas of a field.

As they were being written, all of the lessons were tested and edited by Susan Aldrich-Markham. All of the lessons, glossary, tips and tricks, and appendices are located in Appendix B.

Lesson Descriptions

Lesson 1 introduces the grower to ArcCatalog and ArcMap. Growers learn how to navigate the software and work with different spatial data types. After learning how to add data to a map in ArcMap, growers learn about key concepts such as layers, data frames, saving data and maps, symbolizing data, accessing table information, and selecting features on the screen. Accessing various layer properties such as labeling, symbolizing, and transparency are also addressed in this lesson. Finally, growers are introduced to spatial bookmarks as a method of saving the spatial extent of a specific farm or field.

Lesson 2 shows growers how to use the Editor toolbar to edit farm field boundaries. Grower field boundaries can change as growers sell or lease different fields, change crops, or leave certain areas dormant. Growers can get a free digital copy of their farm field boundaries from the FSA, which are called Common Land Unit (CLU) layers, or they can collect them using GPS. In this lesson, growers use a previously created field boundary so they can learn how to select a specific field and make a new layer with the selected field for use in editing. Growers were introduced to a customize tool called the "Acreage Tool" (Bricker 2005), and they learned how to add it to their interface. The Acreage Tool was created to automate the process of adding and updating an acreage column in a field boundary table. At the end of the lesson growers have the ability to work with their own farm data to manipulate field boundaries.

Growers desire the ability to print out a map to give to their fieldmen or consultants for use in field operations. Therefore, lesson 3 introduces growers to map layouts, templates, and printing a farm map. Growers are first taught how to make a farm map including a NRCS soil type data layer, symbolize and label it based on soil type, make the layer transparent to be able to see other layers underneath, and to set up the map layout. In setting up the map layout, growers learn how to add map elements such as a north arrow, scale bar, and legend. Finally growers add a legend, print the map, and save a map template. Map templates are introduced as a method for quickly reproducing and setting a specific design for farm maps.

Precision agriculture data are collected in many formats, most of which ArcCatalog and ArcMap can only read after they are converted into an ArcGIS specific format. Precision agriculture yield data are collected in a raw format sometimes containing errors and missing data. Therefore, in lesson 4 growers are taught how to manually remove incorrect yield points and prepare yield data for mapping by selecting yield data based on specific parameters. The lesson teaches growers how to set the projection of yield data and reproject it, as most yield monitor software does not include this information with the data when they are exported. Finally, the lesson demonstrates how to create soil sample data points on the map. The data are collected in a spreadsheet format that has to be converted and plotted on the map before the soil sample data points can be made into a permanent point layer.

Lesson 5 teaches growers how to interpolate point yield data in order to make three yield maps for three years of data from one field. The spatial analyst (SA) extension was necessary for creating yield and soil maps. Growers learn how to turn on the SA extension as well as use the inverse distance weighted (IDW) interpolation technique for creating yield, soil nutrient, and elevation maps. IDW was chosen as the interpolation method to teach due to its simplicity. After learning how to interpolate data, growers then symbolize the yield map based on different yield levels. Using the Reclassify tool in SA, growers reclassify the yield maps to show three zones of the field – high, average, and low yielding areas. Finally growers are taught how to make a spatial trend or composite yield map that displays the areas of high and low yield over three years of yield collection for the field. This is created using the SA Raster Calculator window. The spatial trend for yield data is calculated by finding the average for every map cell of all three years of yield for the specific field (Blackmore et al. 2003).

Once a yield map is made, it is important for growers to learn how to make soil and elevation maps, as yield maps can be combined with this information to help identify yield-limiting factors (Righetti and Halbleib 2000; Bakhsh et al. 2000). Lesson 6 teaches growers how to make elevation and soil nutrient maps, again using the SA IDW algorithm. Growers also learn how to work with raw GPS field boundary files by converting them into ArcCatalog readable format and editing them in ArcMap.

In the final lesson, growers use NRCS data to make a farm map that includes elements of a conservation farm plan. The grower learns how to symbolize hydrologic soils data and to create buffers around streams with anadromous fish, which involves creating a new layer and editing it to add the buffer into the new layer. Anadromous fish are species, such as salmon and steelhead trout, that live in the ocean but return to fresh water rivers to spawn (NOAA 2005). Because of environmental regulations, farming practices may need to be modified in wetlands (areas of hydrologic soils and areas surrounding salmon spawning streams).

A lesson appendix was included at the end of the lessons describing how to add the customized Acreage Tool to ArcMap as well as how to set the projection of

FSA CLU, or farm field boundary, layers. Currently CLU farm field boundary layers are given to growers without projection information, and in order for it to line up with other layers the projection must be set to the North American Datum (NAD) 1983 Universe Transverse Mercator (UTM) Zone 10N (meters). This is the datum used by the FSA when creating CLU layers.

In addition to the lesson appendix, a lesson glossary containing general GIS definitions and information about GIS methods was created. Finally, a "Tips and Tricks" of ArcGIS section was included containing basic information about the software. These tips will help any ArcGIS user to become more efficient with the software.

2.1.2 Workshops

The compiled GIS lessons were presented in collaboration with Susan Aldrich-Markham to a pilot group of 16 growers, agricultural fieldmen, and consultants in a series of three workshop meetings. Aldrich-Markham invited growers that had yield monitors, as well as fieldmen and consultants who had already shown an interest in precision agriculture. Participants included 12 grass seed growers from 10 farms in Polk, Yamhill, Benton, and Linn counties, three precision agriculture fieldmen from Wilbur-Ellis and Western Farm Service companies, one private precision agriculture consultant, and one OSU Extension seed specialist.

The workshops occurred on three consecutive Saturdays January 22, 29, and February 5, 2005 from 8:30am – 12:30pm, in the Digital Earth classroom of the Geosciences Department at OSU (http://dusk.geo.orst.edu/de). The Digital Earth classroom was set up for the workshop by loading the data for the lessons on the computers prior to the class as well as making login accounts for each participant. OSU Extension provided lunch for all three Saturdays. The registration fee for the workshop was $40.

Each participant received a lesson notebook with a printed copy of the lessons, glossary, tips and tricks, and appendix. At the beginning of each workshop, the instructor Keldah Hedstrom gave a presentation on GIS and GPS technologies. Then participants engaged in the GIS curriculum following the steps in the lesson notebook at their own pace. In addition to the lesson notebook, participants received a copy of the book by Ormsby et al. (2004), which includes a CD with a 180-day demonstration version of ArcGIS 9.0. However, the 180-day license only allows the use of the basic ArcGIS 9.0 program. To get a license that allows the use of SA, the author contacted ESRI. The company supplied 15 180-day licenses for use by the pilot group participants. Participants were also given two CDs. One CD had the data for use in the lessons, an electronic copy of the lesson notebook and Power Point slides, and the Acreage Tool file, while the second CD had a copy of the individual grower's farm field boundaries from the FSA.

Due to the study involving research with human subjects, i.e. including the use of evaluations and data from individual farms of workshop participants, OSU required researchers to follow Institutional Research Board (IRB) protocol. It first required any person involved with the research to complete an online course on research with human subjects. Prior to the workshop, an IRB application form was completed describing the study, purpose and procedures, the participant population, risks and benefits to participants, the informed consent process, and confidentiality. At the beginning of the first workshop participants were asked to sign an informed consent document, an authorization form for the use of pictures taken of participants during the workshop meetings, and an evaluation consent form allowing researchers to use their evaluations for research purposes. If a participant did not want to sign these documents, they could still participate in the workshops but their evaluations, photos, and data would not be included in this thesis. Susan Aldrich-Markham was the principal investigator in completing the IRB protocol requirements. All IRB documents can be found in Appendix C.

Workshop Descriptions

An outline for the workshop meetings and Power Point slides presented can be found in Appendix D. The first workshop began with an introduction by Keldah Hedstrom and Susan Aldrich-Markham to the project and goals of the research. IRB procedures were explained to the participants and the necessary paperwork was completed. The participants filled out an informational survey. Then Hedstrom gave a presentation on the basics of ArcGIS 9.0 including information on GIS functions, data storage (vector vs. raster data), and data attributes. Participants then worked on Lessons 1-3, at his or her own pace, while Hedstrom gave individual help as needed.

During the second workshop, Hedstrom presented the concepts of coordinate systems, projections, and GPS data collection. Participants then completed Lesson 4. A second presentation, shown before participants completed Lesson 5, discussed the spatial analyst extension and the concept of spatial data interpolation. Two methods of interpolation, IDW and kriging, were discussed. Although kriging was not utilized within the lessons for making yield maps, it was explained as another more complicated but effective method for data interpolation. The presentation also addressed how to choose an appropriate raster cell size.

During the final workshop meeting, Hedstrom presented instructions on how to make a new data layer, save layer symbology, and gave tips for working with ArcGIS 9.0. Afterwards participants completed Lessons 6 and 7 (Figure 2.1 and 2.2). For the last two hours of the workshop, a discussion was held about: 1) what participants would like to be able to do with precision agriculture GIS and GPS technologies in the future and 2) what they perceived to be barriers to adoption of these new technologies by grass seed growers. The ideas were recorded on a newsprint easel as they were being discussed.

Photo by Susan Aldrich-Markham

Figure 2.1. Instructor Keldah Hedstrom helping a workshop participant.

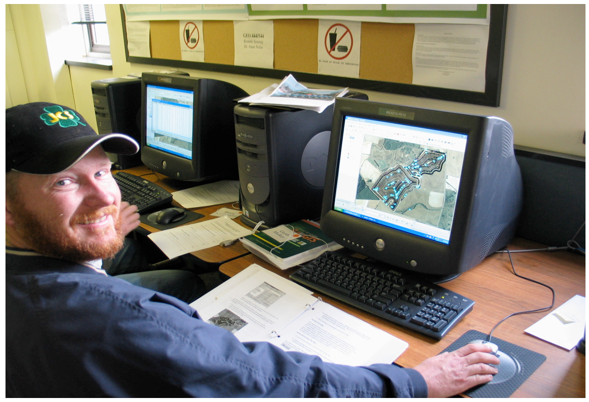


Photo by Susan Aldrich-Markham

Figure 2.2. GIS workshop participant working on a lesson.

After the workshops, Hedstrom maintained contact with the participating growers. She completed four farm visits to help install ArcGIS 9.0 and troubleshoot problems growers had using the program.

2.1.3 Evaluations

Evaluations were created to solicit feedback and measure participant learning. The feedback was used to identify additional tasks growers want to be able to accomplish in ArcGIS 9.0 and to determine if growers used ArcGIS 9.0 on their farms after the workshops. To measure learning, (or to judge whether the lessons were written at the correct level of difficulty for growers), participants were asked to complete a self-evaluation assessing their change in level of knowledge and skill related to various topics covered in each workshop session. For each topic they indicated their levels before the workshop and after the workshop on a scale of one to 10. The evaluation forms were handed out before each workshop session; however, participants could complete both the pre and post evaluations at the end of each workshop if they wished.

The delta over time system (DOTS) technique was used to measure pre and post meeting knowledge of individual participants (Lev et al. 1995). Following DOTS, evaluations were designed to measure the level of GIS knowledge of each participant before and after each workshop meeting. The pre-evaluation and post-evaluation questions were tailored to the specific tasks and material covered for each day of the workshop. All pre and post evaluations had a set of similar questions asking participants to rate the workshops on interest, ease of understanding and usefulness, as well as to suggest ways to improve the workshop.

A follow-up survey, mailed out to participants six weeks after the last workshop, was created to assess the level of ArcGIS 9.0 use. The survey asked participants if they had installed ArcGIS 9.0 and or used any of the GIS skills they learned in the workshops to make farm crop management decisions.

Evaluation results were used to determine if participants considered the workshop useful to themselves and or useful to other growers in the Willamette Valley. Susan Aldrich-Markham aided in the development of all the evaluations.

Evaluation Descriptions

The workshop and follow-up survey evaluation forms can be found in Appendix E, including: the participant information survey that was given out at the first meeting, three pre-workshop evaluations, and three post-workshop evaluations that also included the overall evaluation. Each participant was assigned a number that was used in filling out all the evaluations for an anonymous response.

The initial survey asked for information about the participants farm operations, including crops and acreage, computer use, and current precision agriculture applications or equipment in use. The initial survey also asked participants to list and evaluate their skills in farm mapping, yield monitor, and precision application use.

The pre and post evaluations asked participants to rate their knowledge or ability by placing an X at some point on each of two lines scaled from one to 10. For the workshop held on January 22, 2005, participant change in knowledge or ability was measured for these subjects: GIS, ArcGIS 9.0, GPS, imagery, field boundaries, selecting and editing field boundaries, and printing a farm map. For the workshop held on January 29, 2005, participants were asked to rate their knowledge or ability in projections, yield data, interpolation and yield mapping, reclassification of yield maps, creating composite yield maps, and showing soil test data as points on a map. For the workshop held on February 5, 2005, participants were asked to rate their knowledge or ability in elevation maps, soil nutrient maps, GPS data, and buffering streams. The overall post-workshop evaluation, which was also given out at the February 5, 2005 workshop, asked participants to rate the overall interest, instruction, and use of materials learned from the workshop meetings. The evaluation also solicited comments about the workshop as a whole and suggestions for future workshops.

The follow-up survey asked participants if they had installed ArcGIS 9.0 on their farms, if they had had any interaction with agencies such as FSA, as well as whether they had been able to use ArcGIS 9.0 for farm or yield mapping. The survey also asked for participant indication of their perception of the positives and negatives of ArcGIS 9.0 software, if they planed to purchase it or other precision agriculture software, and if there were any other precision agriculture software packages they would like to learn. Finally, the survey asked if the workshop increased participant interest for using GIS on their farms, if they thought other growers might be interested in a similar type of workshop, and if they had any suggestions for future workshops.

Following the DOTS method, the pre and post evaluation question ratings were entered into S-PLUS 6.1 for Windows. For each question pair of pre and post ratings, a Two-Sample Paired T-test was completed in S-PLUS to determine if a change in knowledge or skill had occurred from the workshops. The Two-Sample Paired T-test was used because the evaluation question rating data represents one population of individuals (i.e. the workshop participants) and contained paired responses (the before and after rating scores) for each question (Ramsey and Schafer 2002).

2.2 Results

2.2.1 Lessons

Creating the lessons was a lengthy process that occurred over the course of the summer of 2004. Some of the lesson tasks could not be easily completed within ArcGIS 9.0. For example, finding the average yield for each soil test point in a field involved multiple steps. Calculating the acreage of a field was a multiple-step process as well. To automate this process, an acreage tool was programmed by an outside resource. The additional SA extension of ArcGIS 9.0 was required to make yield and soil nutrient maps.

2.2.3 Workshops

The discussion held at the end of the last workshop was one of the most important components of the workshop series. During this discussion, a list of ideas about what the growers wanted to be able to do in the future with precision agriculture GIS and GPS technologies was generated. Ideas included:

- Collecting color, black and white, and near infrared aerial and satellite imagery for analysis. Growers suggested using the imagery for measuring crop disease pressures, crop irrigation efficiency, and crop density for PGR variable rate applications.
- Creating variable rate application maps for different chemicals and fertilizers from soils, imagery, yield, and elevation maps.
- Planning irrigation placement by utilizing drainage surface and elevation maps.
- Calculating acreages for possible rental properties to determine yield potentials.

Using the ideas generated in this discussion, as well as in discussions with individual growers during the workshops, a plan of work for Sections 3 and 4 of this research were developed.

The participants also generated a list of barriers to adoption of precision agriculture GIS and GPS technologies. Technology barriers were identified as:

- Time – Growers lacked the time required to learn, work with, and incorporate GIS technology into their operations.
- Upfront Costs – The costs of precision agriculture technology was very high for some growers. Costs included purchasing software, yield monitors, precision equipment, and the actual opportunity cost of the grower’s time.

- Investment – There has been no documentation indicating a financial return of investment from precision agriculture technologies in grass seed. Many growers were left wondering if or when the technology will generate profits.

- Learning – Many growers found precision agriculture technologies and equipment to be very difficult to learn and operate.

- Technical Support – Growers expressed that there is a lack of technical support for precision agriculture technologies and equipment, especially when it becomes broken.

2.2.2 Evaluations

The workshop evaluation responses and follow-up survey responses can be found in Appendix F. Evaluations were received from all 16 participants. For all ability-rating questions administered, (see Table 2.1), there was a significant difference in mean response of the participant group pre-workshop rating score (between 0-10) and post-workshop rating score (p-values range from 0 to 0.03). The results suggest that, on average, the group of participants experienced a positive gain in knowledge and skills from the workshops.

Table 2.1. Measured Learning Results.

Question Number	Knowledge or Ability	Average Change	95% Confidence Interval	P-Value
January 22nd				
1	Understanding the concept of geographic information systems (GIS)	1.9	0.66 - 3.18	0.0059
2	Understanding the concept of global positioning system (GPS)	0.9	0.14 - 1.69	0.0242
3	Familiarity with ArcGIS	2.4	1.73 - 2.98	0
4	Examining aerial photos on a computer	1.4	0.47 - 2.33	0.0065
5	Examining field boundaries on a computer	1.4	0.57 - 2.30	0.0035
6	Editing farm field boundaries on a computer	2.3	1.16 - 3.34	0.0008
7	Selecting a field boundary and creating a new map layer	2.3	1.12 - 3.44	0.0011
8	Examining a soils map on a computer	2	1.18 - 2.87	0.0002
9	Printing a farm map	2.4	0.88 - 3.92	0.0048
January 29th				
1	Understanding the concept of a projection	4.6	3.32 - 5.97	0
2	Understanding the concept of global positioning system (GPS)	1.3	0.14 - 2.52	0.0325
3	Understanding the concept of yield data cleaning	3.2	1.5 - 4.99	0.002
4	Understanding the concept of raster data	3.3	1.79 - 4.88	0.0007
5	Understanding the concept of interpolation	3	1.64 - 4.41	0.0006
6	Viewing a yield map on a computer	2.1	0.81 - 3.34	0.0044
7	Making a yield map	3.1	1.67 - 4.47	0.0006
8	Reclassifying yield categories by yield level on a map	3.2	1.62 - 4.75	0.0011
9	Making a composite yield map with more than one years' data	3.7	2.35 - 5.07	0.0001
10	Showing data from a table as points on a map	2.7	1.48 - 3.95	0.0006

Table 2.1 (Continued). Measured Learning Results.

Question Number	Knowledge or Ability	Average Change	95% Confidence Interval	P-Value
February 5th				
1	Examining soil test data on a computer	2.7	1.72 - 3.76	0.0001
2	Making a nutrient map from grid-sampled soil tests	3.3	1.90 - 4.76	0.0003
3	Making an elevation map from yield monitor data	3.5	1.96 - 5.06	0.0004
4	Examining a GPS map on a computer	3.7	2.26 - 5.17	0.0002
5	Exporting a file from GPS into mapping software on a computer	3.8	1.97 - 5.7	0.0009
6	Editing a GPS map	3.4	1.8 - 5.02	0.0007
7	Creating stream buffers on a field map	4.5	2.44 - 6.49	0.0005

The greatest learning occurred for the subject of understanding the concept of a projection (average increase of 4.6) and creating stream buffers on a field map (average increase of 4.5). The least learning occurred for the subjects of GPS (average increases of 0.9 and 1.3) and mapping of field boundaries and aerial photos (average increase of 1.4). In some cases, no perceived increase in knowledge or ability was indicated on an evaluation because the participant felt that they were already competent in that area.

Participants found the step-by-step instructions on grass-seed-specific GIS tasks valuable. A few participants thought they could have completed the lessons without instruction, while others needed help to understand the complex structure of the software and data types. Participants liked the strong analytical capabilities, handling of multiple data formats, and custom layer symbology that ArcGIS 9.0 provides. However, many participants expressed that it is not agriculture specific and lacks simplicity.

In the evaluations, participants noted their ideas on both the positive and negative aspects of the workshops. Some commented during the workshops that one of the most important aspects was the ability to network with others. They were able to discuss their ideas about what practices have been utilized in the community as well as what practices have or have not been beneficial. Participants were enthusiastic about learning and gaining skills in a new technology. By the end of the workshops, participants had increased their awareness and interest in using yield mapping on their grass seed farms.

What participants did not like about the workshop was the time investment of attending the workshops, learning the technology, and working with the technology. A few participants noted that they did not have proficient computer skills needed to work with the technology.

The follow-up survey revealed that a majority of the 12 growers who participated in the workshops (9 out of 10 farms) had installed ArcGIS 9.0 on their computers. However, only a few of them had made farm maps or practiced the lessons from the workshops. The growers reported that they had not worked with the ArcGIS 9.0 software at home due to a lack of time, difficulty of the software, and or already having a satisfactory agricultural program.

No grower had used ArcGIS 9.0 to look at yield data and only one grower had interacted with the FSA or NRCS about his farm maps. Growers from three farms reported that they might purchase ArcGIS 9.0, while seven had already purchased or were planning to purchase other agricultural GIS software (FarmWorks or AgLeader).

The growers who indicated an interest in purchasing ArcGIS 9.0 wanted a GIS program primarily for creating maps of their farms. The growers who planned to use other GIS programs wanted to make yield maps and prescription application maps immediately. Half the growers thought that other grass seed growers would be interested in the workshop with ArcGIS 9.0, while the other half of the participants agreed others would be interested but only if an agriculture-specific GIS software program was used for the workshop.

When asked what other agricultural GIS programs they would like to learn, most growers reported that they did not have enough information about other programs to answer the question. Growers said that they would like to use precision agriculture for making appropriate decisions about reducing inputs and raising profits, for understanding field problem areas by yield and soil mapping, and for creating variable rate application maps. For improving the workshop, a couple of growers suggested assigning homework or a project for them to have worked on between meetings so they could become more familiar with the software. They also would have liked an additional lesson section on yield mapping and prescription map creation.

A few participants wanted to continue working with ArcGIS 9.0 to learn tasks beyond what was taught in the workshops. They made the following suggestions for future workshop topics:

- Creating variable-rate prescription application maps
- Learning aerial imagery analysis and interpretation skills
- Learning more advanced map labeling and symbology skills

2.3 Discussion

A unique feature of this research was the involvement of grass seed growers in identifying tasks that grass seed growers want to use GIS technology for on their farms. Extensive discussions with the key cooperating grower while working with the data he provided from his farm were critical in designing the lessons. Discussions with growers participating in the workshops as well as their written responses on the evaluations were used to determine what additional tasks (correlating yield with soil nutrient levels and creating prescription maps) to develop methods for.

In addition to involving growers, discussions with staff members of agencies, particularly FSA and NRCS who work with growers, was important in obtaining information about available spatial data for growers. The extensive interaction with growers, fieldmen, and agencies was important to ensure that the results of the research would be useful to grass seed growers.

ArcGIS 9.0 was chosen because it was thought that, although it was complicated to learn and use, growers would eventually be able to do everything with it that they wanted to do. For the tasks covered in the lessons, this seemed to be the case. The author spent many hours trying to simplify the ArcGIS 9.0 tasks into a series of steps growers could follow. Unfortunately, creating yield and soil nutrient maps required numerous steps, as well as the additional expense of the spatial analyst extension. ArcGIS 9.0 was also difficult and intimidating for the participants who were not already skilled computer users. All the workshop participants felt that

ArcGIS 9.0 was too complicated. However, participants felt that the ability of ArcGIS 9.0 to work with multiple data formats is advantageous.

The additional tasks suggested by the participants in the workshop proved to be even more laborious to accomplish with ArcGIS 9.0. To make it simple to use for growers, it would need to be customized through programming. For this reason, other GIS software packages already customized for agriculture were investigated.

The evaluation results confirmed that the workshops increased participant understanding of GIS and GPS technologies. Participants indicated that the tasks covered in the lessons were useful with the greatest learning occurring for the subjects of projections and stream buffering. Large changes in learning also occurred for GPS data mapping ability. The smallest change in knowledge or ability occurred for the subject of GPS and general field boundary mapping. Participants noted that a large flaw of ArcGIS 9.0 was that in their opinions performing the tasks required multiple mouse clicks. Due to lack of time to invest in learning software, most growers need programs that are simpler. They may only use the program occasionally and therefore may not be able to remember complicated procedures.

The evaluations indicated that overall, the workshops were positively received. Participants responded positively to the format of short presentation, where they were able to ask questions, followed by hands-on exercises where they could continue at their own pace with help from the instructor as needed. Although the participants felt they learned about GIS and GPS from the workshops, many did not like the commitment of three Saturdays in a row.

The lessons as written were at the right level of difficulty for the participants. Although some participants took more time to complete them then others, there were no points at which participants became terribly lost. The lessons might be useable for some other growers to complete on their own.

Some of the participants became frustrated when ArcMap and or ArcCatalog crashed during their lessons. After each workshop meeting the instructors noted the dilemmas that occurred during the meetings and compiled a list for future workshop improvements including:

- Proceeding through the entire first lesson step-by-step, with participants following the instructor. This would have allowed all participants to become more comfortable with the software and to ask questions.
- Showing participants how to organize their data within ArcCatalog at the beginning of the first lesson, as many became confused with the catalog structure.
- Waiting until after the first lesson to give participants their own farm field boundary data, as they would rather look at their own data then the lesson data.
- Confirming that CLU layers (from the FSA) have a defined projection, as they initially would not line up correctly with the other county data.
- Handing out ArcGIS 9.0 installation instructions before the end of the first workshop meeting, as many participants were confused on how to install it at home.

As indicated by the follow-up surveys, growers lack information and instruction in precision agriculture technologies. These technologies cannot simply be released and then expected to be easily used by everyone. New growers trying to use these technologies often become frustrated and quit because they cannot figure the technology out. According to Barao (1992), “Generating knowledge isn’t always synonymous with diffusing and adopting knowledge.” Intermediate steps, such as the training materials and workshops produced in this project, are important as they can aid growers in understanding and using the technologies.

Although the growers were positively engaged in the workshops and the GIS lessons, they did not adopt the technology and begin using it immediately on their farms. The adoption barriers they listed in the discussions (Results section page 27) provide insight as to why adoption of these technologies is not automatic. Some of these barriers are beginning to lessen as costs of software and equipment are beginning to decrease, simple agriculture specific GIS programs are beginning to become available, and more data are becoming available for growers.

However, grower lack of time to spend in learning the technology is still a major adoption barrier. Unless the technology is very easy to use and technical support is readily accessible, many growers have a hard time justifying the expense required to purchase these technologies. Providing additional educational opportunities can help growers to become interested in the technologies and reduce apprehension about software learning difficulties.

Obtaining the technology must be financially feasible and beneficial or adoption of the technology will not occur. Growers in the Willamette Valley have similar concerns to those in the central US in that uncertainty of returns from precision agriculture technology, high costs of adopting the technology, and lack of clear results of site-specific technologies on yields and input-use are major reasons for slow adoption of the technology (Khanna et al. 1999).

According to Arnholt et al. (2001), the primary motivation for precision agriculture technology adoption is “to increase profits by making better management decisions.” The technology may be a good environmental investment but if it is harder to implement and more expensive than it is worth, it is not practical for growers or any other business. As noted earlier, grass seed growers have not seen any financial return on precision agriculture applications. This could be because the technology is still new to the agricultural arena and that there are not enough years of data to see yield-limiting factors or that in some cases precision agriculture is just not profitable. Growers have to make decisions with the spatial data to see if there is a return on precision agriculture technology.

The discussion held at the end of the last workshop meeting was one of the most important components of the workshop as it provided participants with the ability to interact and voice their opinions and exchange ideas about how precision agriculture technologies can be applied to their farms. The participants can now call upon each other for consultation.

The suggestions provided by participants on further GIS tasks of interest to growers for grass seed production were used as the basis for the second part of this research. From these suggestions, additional tasks of determining correlations between soil nutrients and yield as well as creating prescription application maps were added to this research to provide growers methods in ArcGIS 9.0 for accomplishing these additional tasks. The results of this work will be incorporated into further GIS training for growers provided by OSU in the future.

3. Yield and Soil Nutrient Correlations and Prescription Maps

3.1 Yield and Soil Nutrient Correlations Overview and Methods

The basic premise of precision agriculture is that crop yields vary spatially across a field. Yield within a field is limited by some factor, or group of related factors, and different limiting factors can control yields within different fields (Lark and Stafford 1997; Jaynes and Colvin 1997; Kravchenko et al. 2003; and Jiang and Thelen 2004). Soil nutrients are thought to be one of the most amenable to management using precision agriculture (Frogbrook et al. 2002; Perez-Quezada et al. 2003; and Lark and Stafford 1997). Mapping of soil nutrients is usually one of the first steps, along with yield mapping, for a grower in the implementation of precision agriculture technologies.

On the workshop evaluations, growers indicated that, in addition to what they learned from the workshop, they wanted to be able to determine relationships between yield, soil nutrient levels, and elevations with GIS. Therefore two specific research questions were created to address the needs of growers including: **1) Are there spatial relationships between yield, elevation, and soil nutrients in three grass seed fields in the Willamette Valley? 2) Is the yield in a field high in the same areas as a specific soil nutrient (potassium for example) level is high?**

In order to help growers determine if relationships exist between soil nutrients, elevation, and yield, GIS and linear regression analyses were used to compare yield and soil nutrients for three grass seed fields, Fields 1 – 3, located in Polk and Linn counties. Site-specific data including yield (lbs) and soil nutrient samples were collected and analyzed for all fields.

3.1.1 Data

Yield monitors are the most widely adopted precision agriculture technology (Griffin et al. 2004). Yield mapping, or the digital mapping of yield monitor collected yield data points, allows for the measurement of crop yield variations at specific locations within a field. Creating a digital record of yield variation within a specific field can provide insight as to how field management practices should be adjusted for maximum crop production (Larscheid et al. 1997). Decisions about land rents, drainage tiling, and crop values can also be made using yield mapping (Griffin et al. 2004).

Four years, (2001 to 2004), of grass seed yield data were provided by the key cooperating grower for two fields (Field 1 and 3) and three years, (2001 to 2003), of grass seed yield data were provided for one field (Field 2). The yield data were collected with GPS locations, with a Geographic projection of WGS 1984 (decimal degrees), from a John Deere combine equipped with a GreenStar yield monitor system. The yield data were exported to the ESRI shapefile format from the grower's JDOffice software. Along with yield information, GPS elevations were collected for every yield point and were used in the creation of elevation maps.

Within each yield data shapefile, there were over 40,000 points collected, as one combine reading was taken every second or five feet. Yield data need to be cleaned to remove errors caused by GPS loss of signal, operator error, flux of combine speeds, time lag of grain through the machine, and lack of correct sensor calibration (Blackmore and Marshall 1996; Blackmore and Moore 1999; Thylen et al. 1997). Some of these yield data errors can be fixed by manual correction, while others such as operator error and flux of combine speeds, need to be handled in the field.

ArcGIS 9.0 was used for manual correction of yield data errors that could be removed after yield collection. The grower determined that yield should not be below 200 lbs or above 3000 lbs for each field. These yield levels were used to remove all points that fell outside of the acceptable range of yield for each field. After these points were removed, each row of seed yield was manually inspected for incorrectly placed yield readings. For example, areas in the field where the combine turns a corner may have incorrect yield readings due to the combine not actually collecting seed but issuing readings from seed previously collected. This resulted in removing around 4000 points per year of yield per field.

A private consulting company collected soil nutrient samples for the grower at specific locations within all three fields during the spring of 2004. The consultant collected a soil sample point every 2.5 acres, about 100 points per field. The grower provided soil nutrient tests results of every soil sample GPS point recorded per field in an Excel spreadsheet. For utilization in ArcGIS 9.0, the Excel spreadsheet was converted to dBase format, a format readily interpreted by the software. The dBase file was brought into ArcMap and a new point shapefile was created for every field by mapping the latitude and longitude values and exporting the points.

With both yield and soil nutrient sample point layers open in ArcMap, a spatial location search was used to locate and select all those yield points, for all years of yield for every field, falling within a 60ft radius of each soil nutrient sample point. The 60ft radius length was selected as this encompassed at least two paths of yield data collection. The selected yield points were exported to a new shapefile and the average yield for each soil nutrient sample point was calculated and recorded in an Excel spreadsheet.

3.1.2 Regression Analysis

Following the methods of Bakhsh et al. (2000), Kravchenko and Bullock (2000), Kaspar et al. (2003), Perez-Quezada et al. (2003), and Berry (2002), a linear regression approach to correlate soil nutrients with crop yield was used to determine if yield variability can be explained by soil nutrients. Initially, it was thought that linear regression analyses between yield, elevation, and soil nutrients levels could be easily completed using ArcGIS 9.0. It was discovered that linear regression correlations with point data could not be easily completed in ArcGIS 9.0 without additional programming. It was noted that soil nutrient and yield raster data could be correlated using tools such as the SA Band Statistics Collection tool in ArcToolbox. However, due to the difference in scales of data collection this was not pursued and specific locational correlations between average yield and soil nutrients were completed in Excel.

An Excel spreadsheet of soil sample nutrient points and average yield data for each field can be found in Appendix G. Average yield per soil point was determined instead of comparing yield and soil interpolated surfaces due to the differences in scale of data collection. In Excel the various years of yield, elevation, and soil nutrients Potassium (K), Magnesium (Mg), Phosphorous (P), Calcium (Ca), and buffer were graphed as scatter plots for each field. Linear regression and R-squared values were then calculated for each combination of yield and input. Yield comparisons were restricted to years 2003 and 2004, as these were the closest to the date the soil samples were collected. After the regression analysis was completed, the results were shown to an OSU Extension soil specialist for advice in interpretation.

3.1.3 ArcGIS 9.0 Maps

Within a GIS, yield, soil type, and topographic layers can be delineated and integrated in an attempt to determine spatial (locational) and temporal (time) variability in crop yields (Righetti and Halbleib 2000; Bakhsh et al. 2000; and Roel and Plant 2004). Soil and yield maps created in a GIS can be used to visually evaluate spatial patterns of yield and soil within a field. Sometimes visual inspection of a field may reveal anomalies or patterns that were not found through statistical analysis. In order to provide the grower with a visual spatial representation of Fields 1 - 3 used in the regression analysis, yield, soil nutrient, and elevation maps were created for each field using ArcGIS 9.0.

GPS-collected yield and soil test nutrient data need to be interpolated in order to create a smoothed surface map of the collected point data. A robust method of interpolation is the geostatistical method of kriging (Roel and Plant 2004; Jaynes and Colvin 1997; Frogbrook et al. 2002; Dobermann and Ping 2004; Sudduth et al. 1997).

In this project, kriging was utilized to make smoothed surface maps of soil nutrients, elevation, and yield data. Kriging was used because it has the ability to fit multiple data points and use local means instead of global means when predicting new values. For a complete explanation of the geostatistical interpolation method of kriging, see Frogbrook (2000).

In ArcGIS 9.0, the SA extension and the ordinary spherical kriging algorithm was used to create elevation, yield (2003 and 2004 for Fields 1 and 3 and 2003 for Field 2), and soil nutrient maps. A cell size of 100 ft was used in creating all grids due to the large size of the fields and units needed for crop management. A large cell size allows a grower to look at field trends that can be managed with large field equipment. For the soil nutrient kriging operation the number of neighboring points used was 6, and the maximum distance used in searching for points was 350 ft (because each point is about 300 to 350 ft apart). For the yield kriging operations, the number of neighboring points used was 12, and the maximum distance used in searching for points was 70 ft as the points are closer together. For the elevation kriging operations, the GPS elevation recorded within one yield data file per field (2002 for Field 1, 2003 for Field 2, and 2004 for Field 3) was used to create one elevation map for each field. For elevation kriging, the number of neighboring points used was 12, and the maximum distance used in searching for points was 70 ft.

The yield maps were reclassified using the Reclassify tool in the SA extension. Following methods of Berry (1999), all yield maps were reclassified to have three classes of below average yield, average yield, and above average yield levels. Yield data were separated into classes based on the average and standard deviation (SD) of yield for each field. Classes were separated using the Classification Window of the Reclassify tool (Figure 3.1), for each yield map.

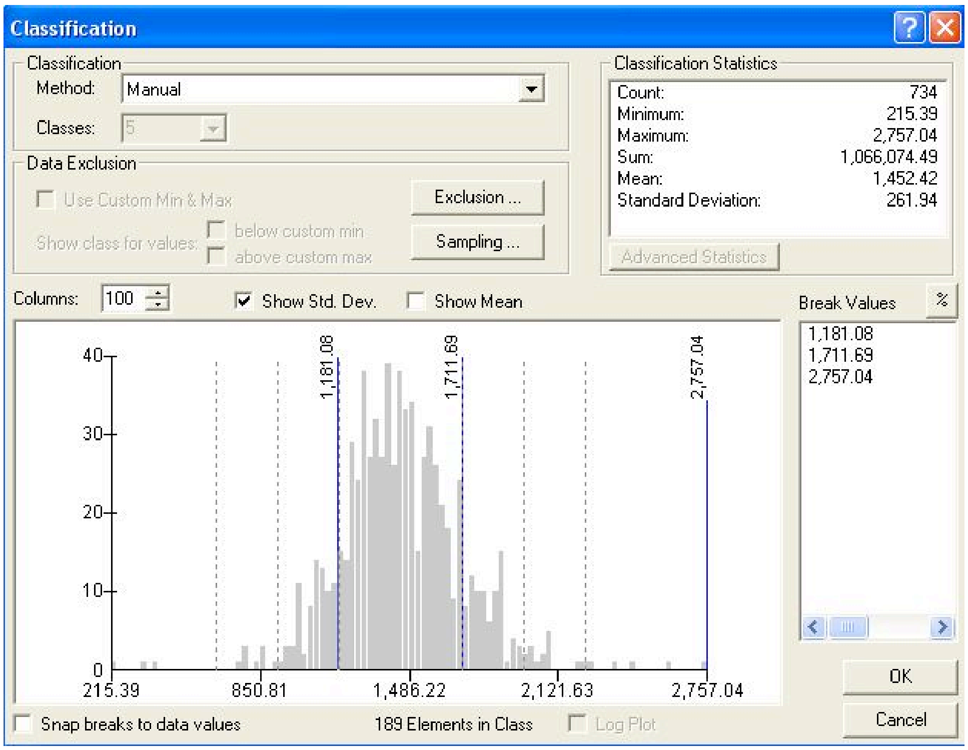


Figure 3.1. Classification window of the SA reclassify tool.

All yield within one SD of the average was assigned to the average class (3) while all yield below one SD was assigned to the below average class (1) and all yield above one SD was assigned to the above average class (5) (Table 3.1).

Table 3.1. Yield Reclassifications.

Yield Class	Yield Level
1	Below Average Yield
3	Average Yield
5	Above Average Yield

However, a grower can use his or her knowledge about the average yield levels of a field to change the yield levels used to reclassify the map.

Soil nutrients were also reclassified using the Reclassify Tool in SA. Nutrients K, Mg, P, and buffer were used for reclassification due to their importance in grass seed production. Information from the OSU Fertilizer Guide for Perennial Ryegrass Grown for Seed FG 46-E by Hart et al. (2005) was used to determine high levels of nutrients for creating reclassified soils maps to show high and low levels of nutrients in each field. High nutrient levels, displayed in Table 3.2, were used as the cutoff values for reclassifying soil nutrient data.

Table 3.2. Nutrient Levels Used in Reclassification of Soil Maps.

Soil Nutrients	High Nutrient Levels
Phosphorous (P)	15 ppm
Potassium (K)	150 ppm
Magnesium (Mg)	60 ppm
Buffer	6.2

For example, all those K values below 150 (low nutrient levels) were reassigned to a value of zero while values above 150 (high nutrient levels) were reclassified to a value of one (Table 3.3).

Table 3.3. GIS Reclassifications.

Soil Nutrient Class	Soil Nutrient Level
0	Low Level
1	High Level

GIS can be used to perform overlay analyses in an attempt to understand the basis of spatial variation within a field (Bakhsh et al. 2000). In this project methods for binary overlay analysis with soil and yield data were used. A binary grid is a grid that has been reclassified to meet a condition (given a class of 1) or not (given a class of 0). This binary grid can then be added, multiplied, divided, subtracted, etc. with another grid to create a new grid showing where specific conditions have been met. For a detailed description of GIS binary overlay analysis, see Berry (1995).

In the SA Raster Calculator, the reclassified yield maps were added to the reclassified soil nutrient maps to show those areas of the field with different combinations of yield and nutrient levels. For example, a K map with 1 = values above 150 (high nutrient level) and 0 = values below 150 (low nutrient level) was added to a yield map with 1 = below average yield, 3 = average yield, and 5 = above average yield. The resulting grid had values of 1 – 6 with each value representing a unique combination of nutrient levels and yield (Table 3.4).

Table 3.4. Resulting GIS Reclassification Map Combinations.

Reclassified Value	Reclassified Meaning
0 SN + 1 Yield = 1	Low Nutrient and Low Yield
1 SN + 1 Yield = 2	High Nutrient and Low Yield
0 SN + 3 Yield = 3	Low Nutrient and Average Yield
1 SN + 3 Yield = 4	High Nutrient and Average Yield
0 SN + 5 Yield = 5	Low Nutrient and High Yield
1 SN + 5 Yield = 6	High Nutrient and High Yield

Finally, spatial trend, or composite, yield maps that show areas of the field with high or low yields over a series of years of data collection were created (Blackmore et al. 2003). Spatial trend maps were created using the SA Raster Calculator. In the Raster Calculator, a math equation was used to compute the average of all years of yield available to create the spatial trend yield maps. Following the methods of Blackmore et al. (2003), an example of the math equation used for creating spatial trend grid maps includes: ([Yield03]+[Yield02]+[Yield01])/3. A yield spatial trend map was created for Field 1 from years 2001 to 2003, Field 2 years 2001 to 2003, and Field 3 2001 to 2004.

3.1.4 Results

3.1.4.a Regression Analysis

Initially, it was thought that correlations could be completed in ArcGIS 9.0. Scatter plots could be completed with ArcGIS 9.0, however, correlations could not without additional programming or scripting. Therefore, Excel was used to complete correlations rather than ArcGIS 9.0.

As indicated by the low to zero r-squared statistics, soil test nutrients K, P, Mg, Ca, buffer, and elevations were not correlated with grass seed yield, from yield years 2003 and 2004, for Field 1. As indicated by the regression graphs for 2003 yield and the above mentioned soil properties, (Figure 3.2), there were no unusual or outlying values of yield, elevation, or soil nutrients. Regression graphs for Field 1 2004 yield and soil properties can be found in Appendix H.

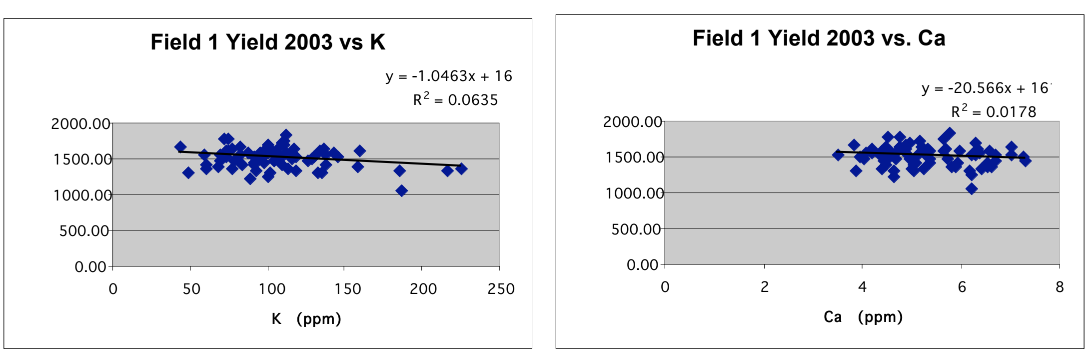


Figure 3.2. Soil properties and 2003 yield regression graphs for Field 1.

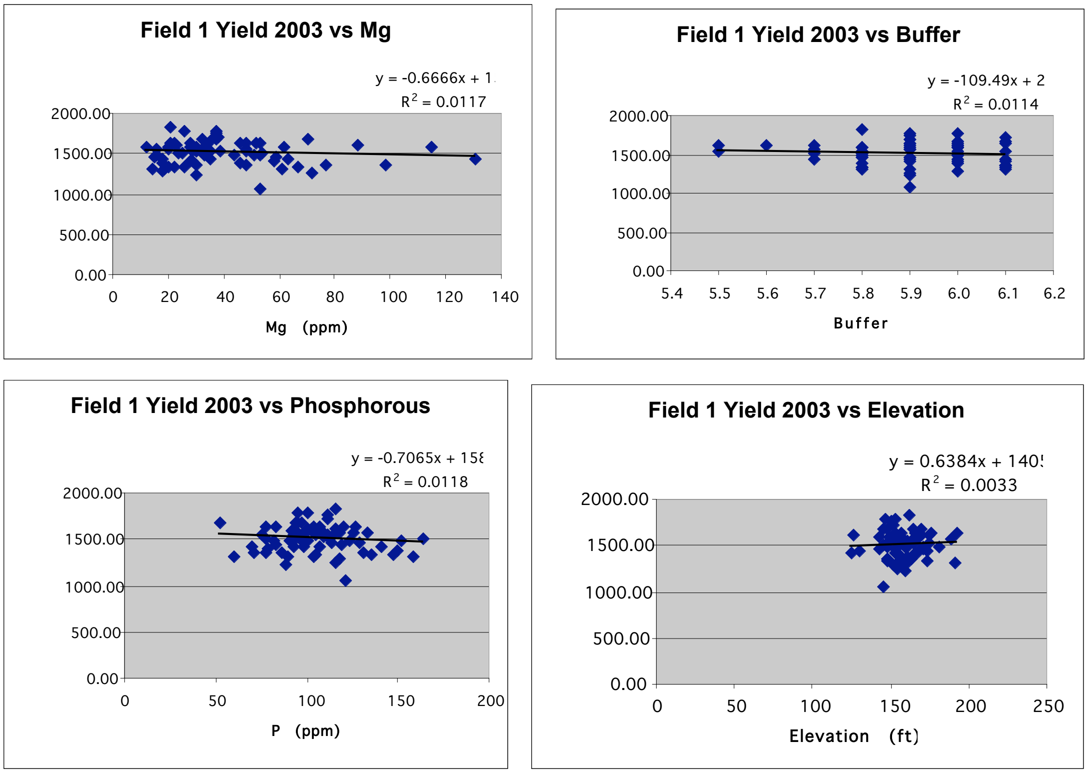


Figure 3.2 (Continued). Soil properties and 2003 yield regression graphs for Field 1.

As indicated by the low to zero r-squared statistics, soil test nutrients K, P, Mg, Ca, buffer, and elevations were not correlated with grass seed yield, from 2003, for Field 2. As indicated by the regression graphs for 2003 yield and above-mentioned soil properties, (Figure 3.3), there were no unusual or outlying values of yield, elevation, or soil nutrients. Yield was only collected for 2003 for Field 2; therefore no additional graphs were created for Field 2.

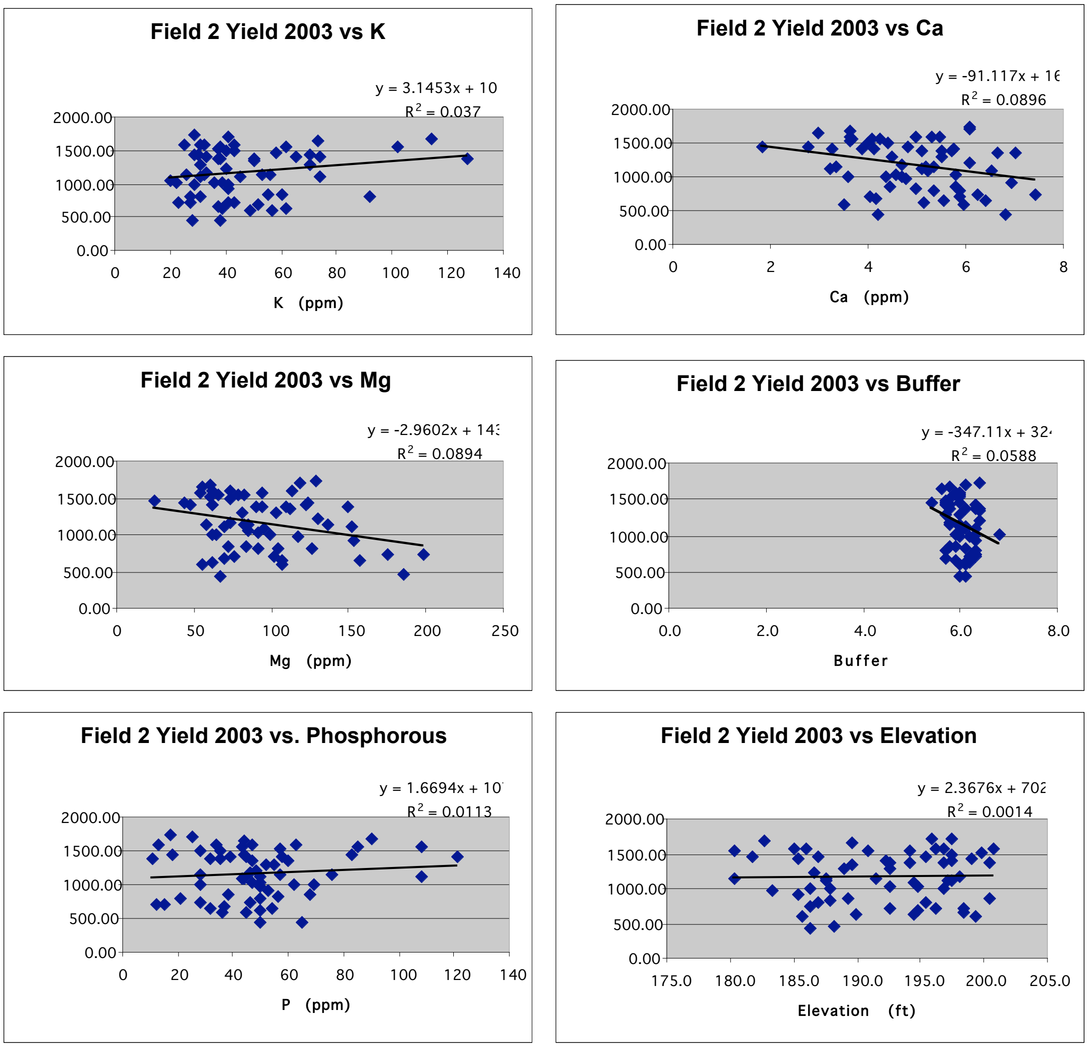


Figure 3.3. Soil properties and 2003 yield regression graphs for Field 2.

As indicated by the low to zero r-squared statistics, soil test nutrients K, P, Mg, Ca, buffer, and elevations were not correlated with grass seed yield, from yield years 2003 and 2004, for Field 3. As indicated by the regression graphs for 2003 yield and above-mentioned soil properties, (Figure 3.4), there were no unusual or outlying values of yield, elevation, or soil nutrients. Regression graphs for Field 3 2004 yield and soil properties can be found in Appendix H.

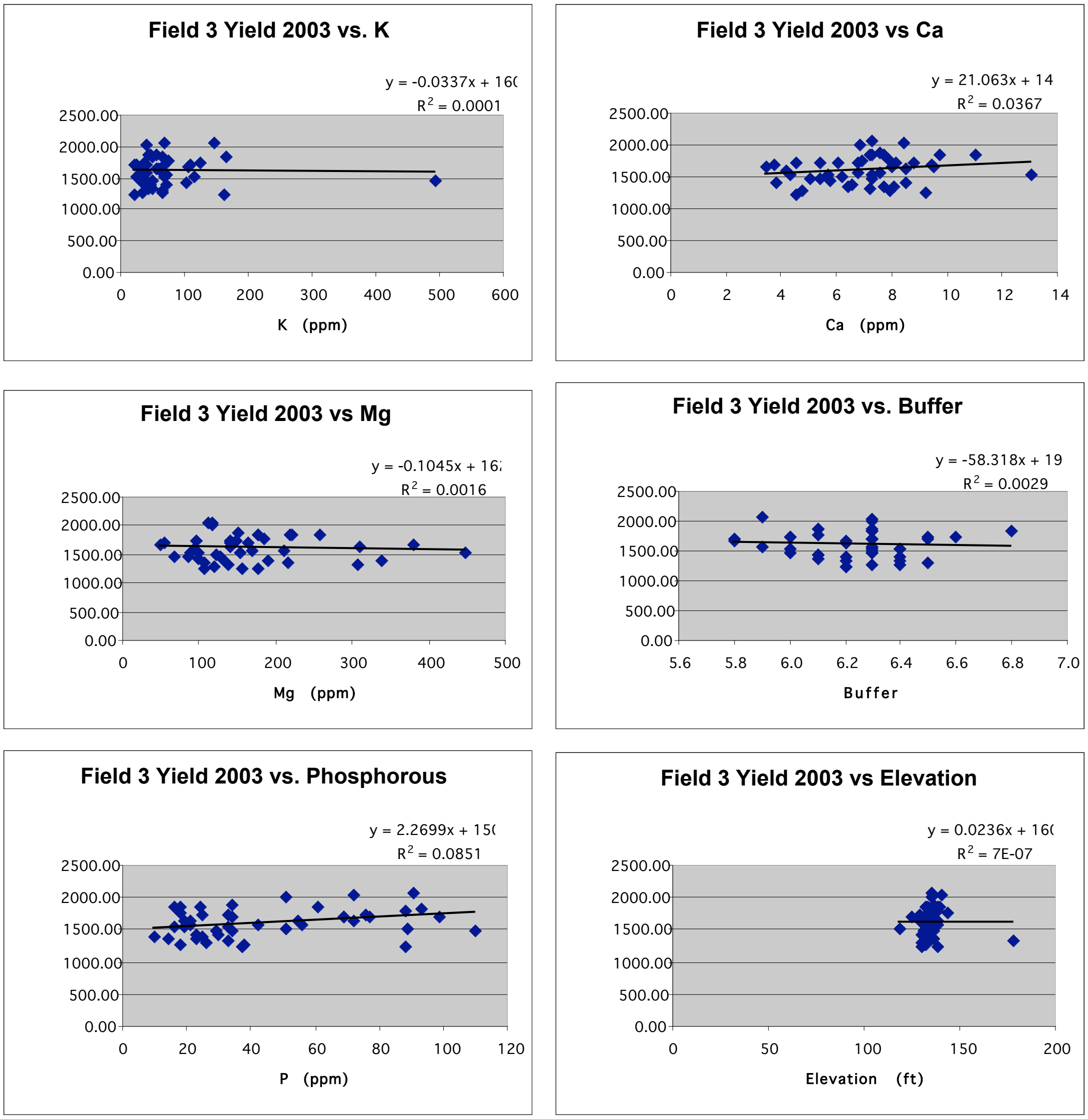


Figure 3.4. Soil properties and 2003 yield regression graphs for Field 3.

Elevation data were collected within the range of variability of the combine GPS receiver (1 to 5 feet) and therefore might not be accurate enough for correlation analyses. Therefore, correlations with yield and elevation data collected by a combine GPS unit might not be as accurate as if elevation measurements were collected with survey grade GPS.

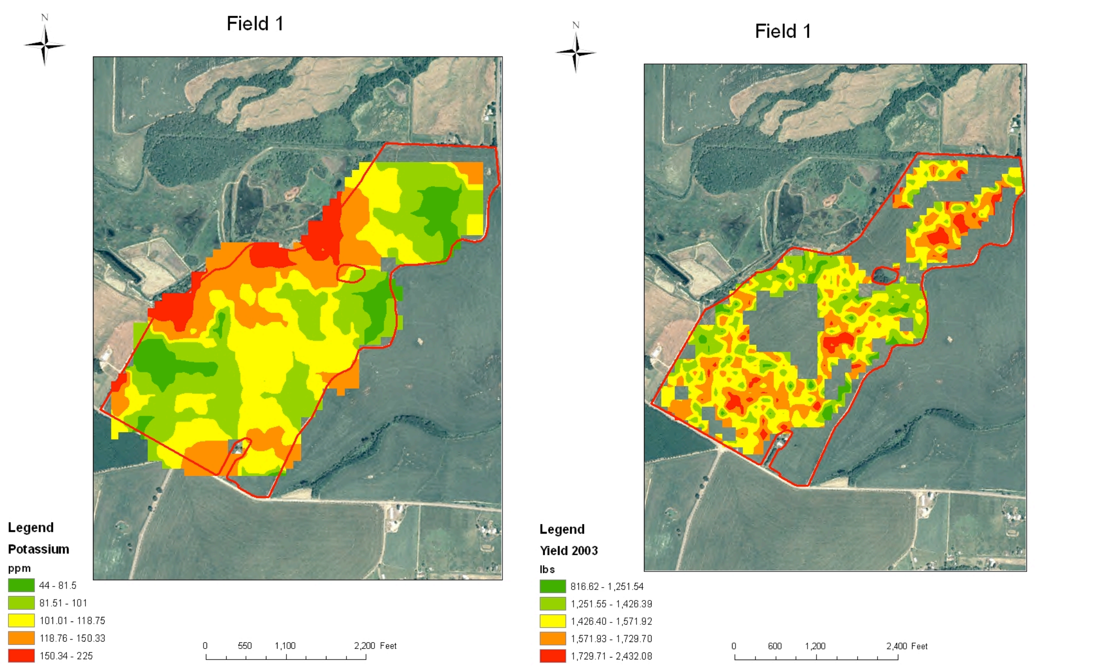
In discussing the regression analysis with the OSU Extension soil specialist, it was determined that soil nutrients were not the limiting factor for yield variability within all three fields (pers. comm. J. Hart 2005). In all of the fields the K levels were low and the grower responded by making a potash application that season. However, these levels were not so low that they had started to affect yield levels.

Finding no correlation between soil nutrient levels and yield in a field is still a useful result for growers. They could then reason that spending extra money on variable rate applications of fertilizer will not likely provide a financial return by increasing yield, which is an important management decision. If the limiting factor for yield in a field is not nutrient levels, then some other factor or combination of factors should be investigated to determine what might be controlling yield variability within each field.

3.1.4.b ArcGIS 9.0 maps

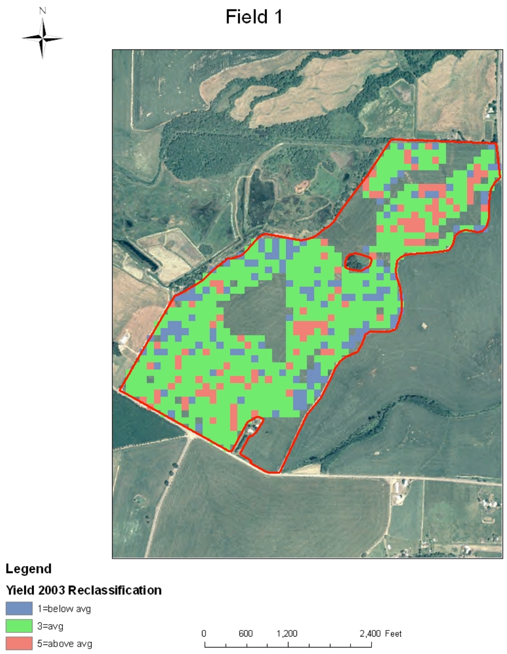
ArcGIS 9.0 maps were created to demonstrate how the software could be used to visualize the spatial distributions of yield, elevation, and soil nutrients for several fields. Even though the yield and nutrients did not show any significant correlations, viewing the spatial distributions of yield and nutrients might still provide valuable information about a field that might not be determined through correlation analysis. Spatial mapping of yield and nutrients can show potential field problems such as water pooling areas, weeds, and pest infestations. The method of creating soil, yield, reclassification, and combination maps was found to be flexible, allowing growers to alter the maps as they see fit.

Soil K, P, Mg, buffer, elevations, yield, and soil-yield combination maps were created in ArcGIS 9.0 for Field 1. Example soil K, 2003 yield, soil K reclassification, 2003 yield reclassification, and soil K- 2003 yield combination maps can be found in Figure 3.5. All other maps of Field 1, including other soil nutrients, 2004 yield, soil and yield reclassifications, and soil-yield combinations can be found in Appendix I. Yields for 2003 and 2004 were not collected over the entire field. Yield monitor and GPS data collection malfunction is a common problem for growers. Lack of yield collection affected soil-yield combination creation, as only those areas with collected yield and soil samples were compared. A spatial trend or composite yield map was not created for Field 1 due to the spotty yield collection over years 2003 and 2004.

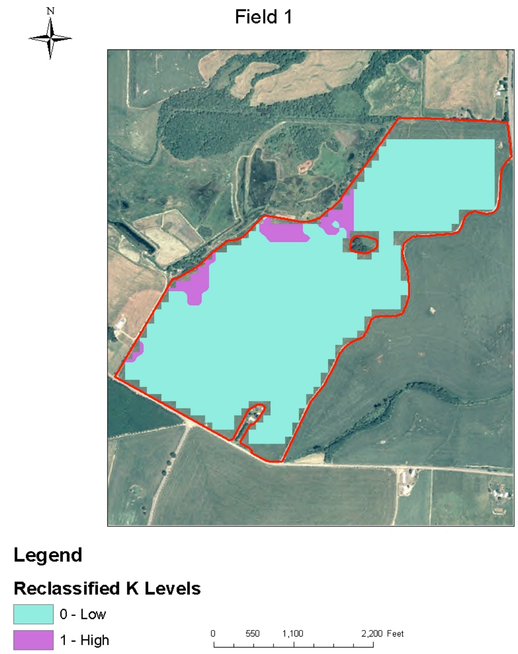


a) Soil K map b) 2003 yield map

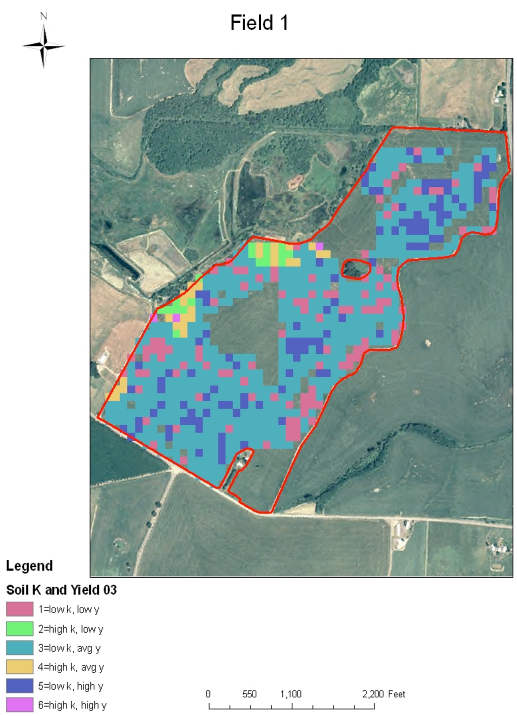
Figure 3.5. Example ArcGIS 9.0 maps of Field 1: a) Soil K, b) 2003 yield, c) Reclassified 2003 yield, d) Reclassified soil K, e) Soil K and 2003 yield combination, f) Elevation.



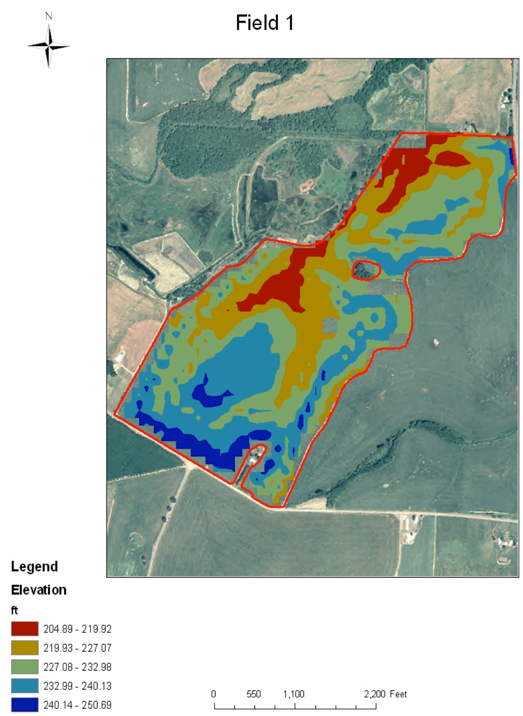
c) Reclassified 2003 yield



d) Reclassified soil K



e) Soil K and 2003 yield combination map

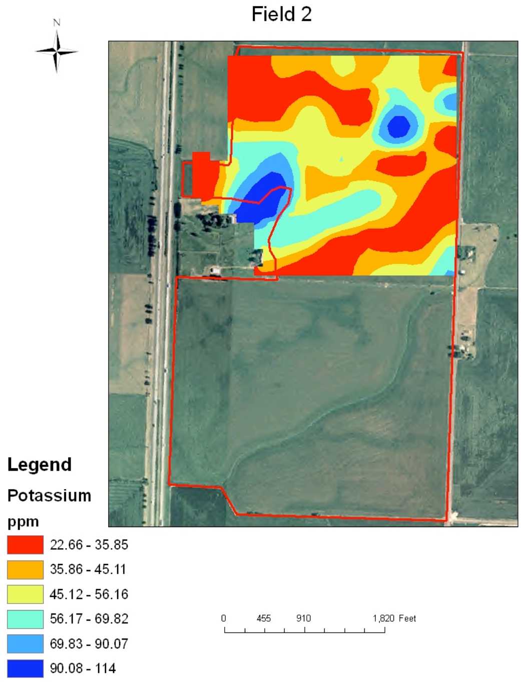


f) Elevation map

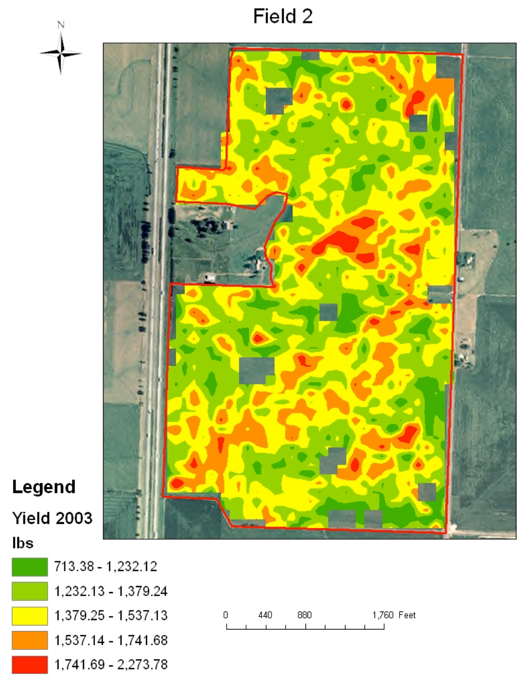
Figure 3.5 (Continued). Example ArcGIS 9.0 maps of Field 1: a) Soil K, b) 2003 yield, c) Reclassified 2003 yield, d) Reclassified soil K, e) Soil K and 2003 yield combination, f) Elevation.

As indicated by the example maps soil K (a), 2003 yield (b), reclassified soil K (c), and reclassified 2003 yield (d), Field 1 soil nutrients and yields were not distributed uniformly over the entire field. There were specific areas of high and low soil K and yields. The soil K – 2003 yield combination map indicated that there were different combinations of high, average, and low yields with low and high levels of K. The western border of the field displayed areas of low K with low and average yields while throughout the field there were areas of low K and high yields with most of the field having low K and average yield. A prescription application of K could help to more evenly distribute this nutrient across the field. Finally, the elevation map of Field 1 indicates a slight hill in the field. Knowing the elevation of the field may help to determine areas under water during the winter months, specifying appropriate locations for drainage devices, and also may be an indication of changing soil types that may affect nutrient availability.

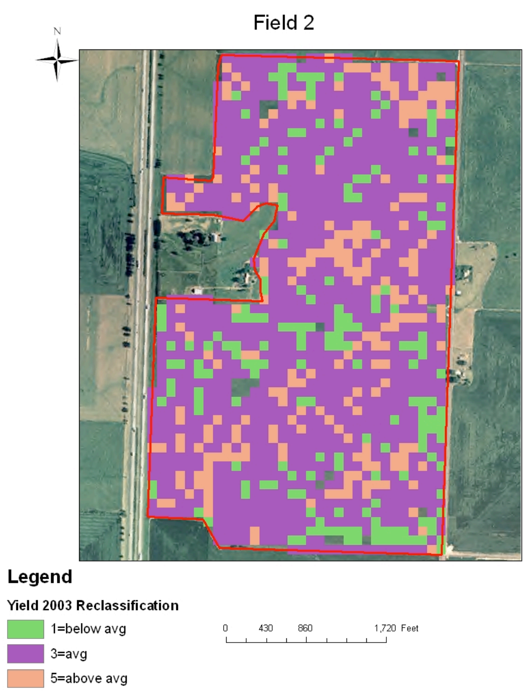
Soil K, P, Mg, Buffer, elevations, yield, reclassified soil, reclassified yield, and soil-yield combination maps were created in ArcGIS 9.0 for Field 2. Example soil nutrient K, 2003 yield, reclassified soil and 2003 yield, soil K- 2003 yield combination, and 2001 – 2003 spatial trend yield maps are shown in Figure 3.6. All other maps of Field 2 including soil nutrients, reclassified soil nutrients, and soil - 2003 yield combinations are found in Appendix I. It was noted that soil nutrient sample points were only collected for the northern half of Field 2; therefore soil nutrient, reclassification, and yield combination maps were only created for the north half of the field.



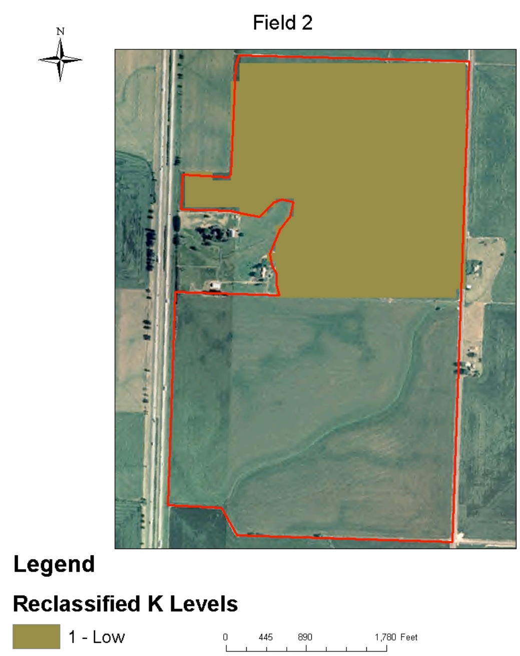
a) Soil K Map



b) 2003 Yield Map

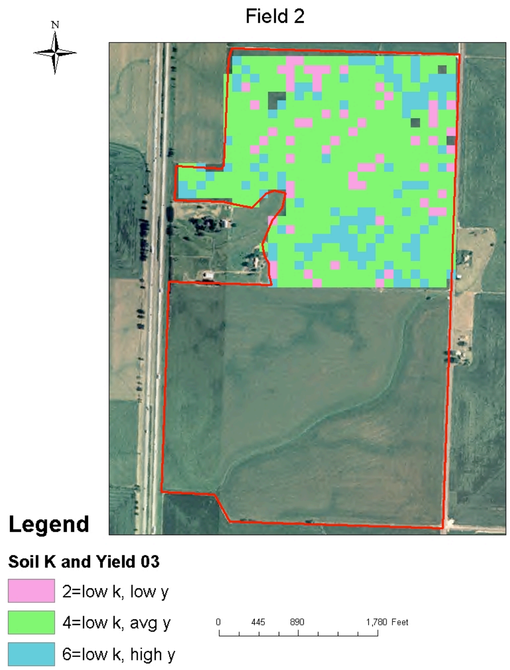


c) Reclassified 2003 yield map

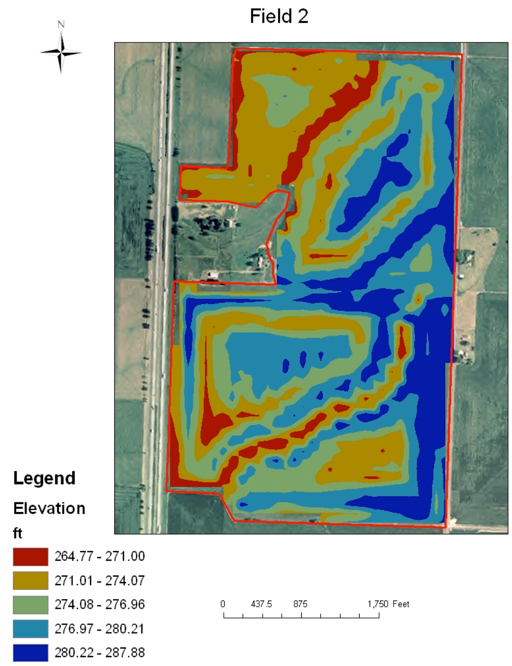


d) Reclassified soil K map

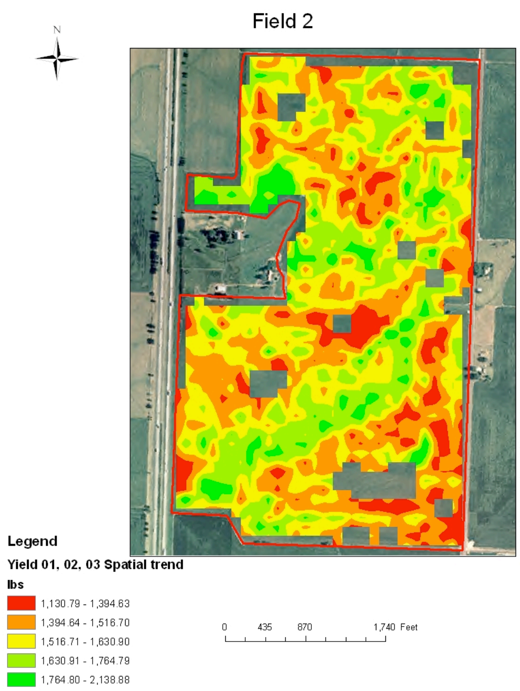
Figure 3.6. Field 2 ArcGIS 9.0 maps: a) Soil K, b) 2003 yield, c) Reclassified 2003 yield, d) Reclassified soil K, e) Soil K-2003 yield combination, f)Elevation, g) Spatial trend.



e) Soil K and 2003 yield combination map



f) Elevation map

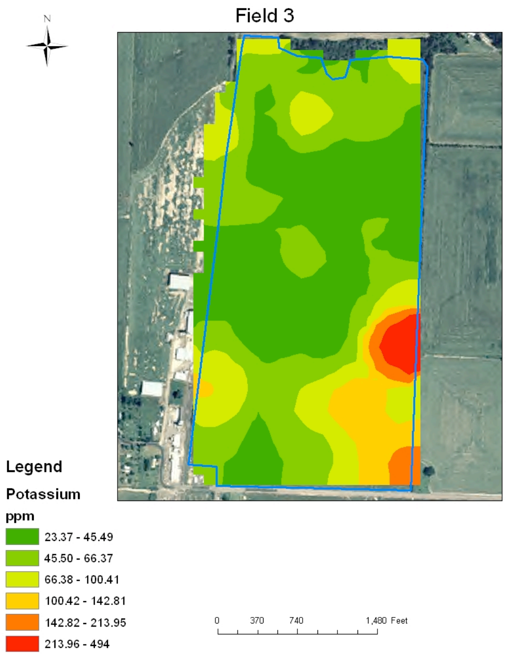


g) Spatial trend 2001 – 2003 yield map

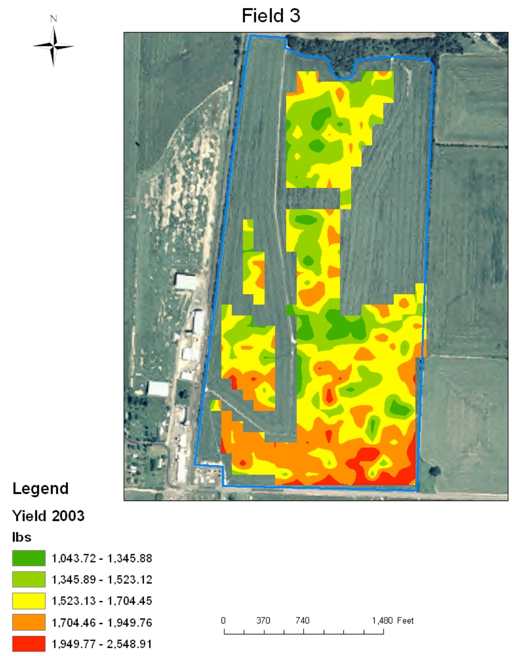
Figure 3.6 (Continued). Field 2 ArcGIS 9.0 maps: a) Soil K, b) 2003 yield, c) Reclassified 2003 yield, d) Reclassified soil K, e) Soil K-2003 yield combination, f) Elevation, g) Spatial trend.

Example maps soil K (a), 2003 yield (b), and reclassified 2003 yield (c), indicate that Field 2 soil nutrients and yields were not distributed uniformly over the field. There were areas of high, average, and low yields while soil K levels were found to be low over the entire area sampled. The soil K and 2003 yield combination map indicated that there were different combinations of high, average, and low yields with low levels of K. There were only small areas of low yields relative to the low levels of soil K. This indicates that soil K probably was not the most important factor controlling 2003 yields within this field. The reclassified soil K map (d), indicated that a uniform application of soil K might be more appropriate than a prescription application of K due to the low level of K over the entire field. The elevation map (f) for Field 2 indicates that higher elevations were recorded in the eastern side of the field. The spatial trend 2001 to 2003 yield map (g) revealed that a pattern of higher yields existed in a south to north diagonal through the middle of the field as well as areas in the top half of the field.

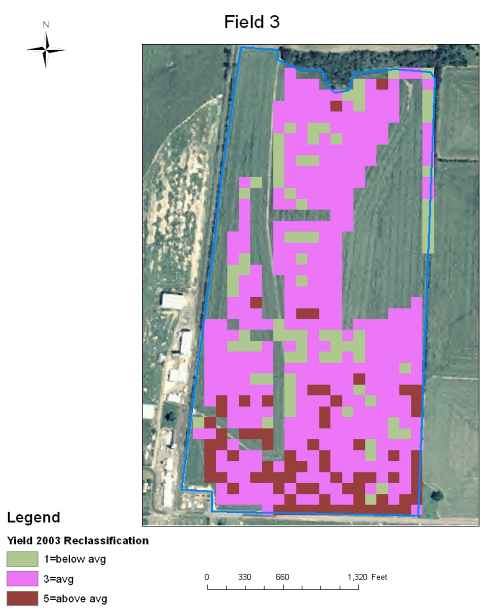
Soil K, P, Mg, Buffer, elevations, yield, reclassified soil, reclassified yield, and soil-yield combination maps were created in ArcGIS 9.0 for Field 3. Example soil nutrient K, 2003 yield, reclassified soil K, reclassified 2003 yield, soil K-2003 yield combination, and 2003 to 2004 spatial trend yield maps are shown in Figure 3.7. All other maps of Field 3 including soil nutrients, 2004 yields, reclassified soil, 2004 yield, and soil-yield combinations are in Appendix I. It was noted that yield for 2003 was not collected for the entire field. Only those areas with collected yield and soil samples were compared.



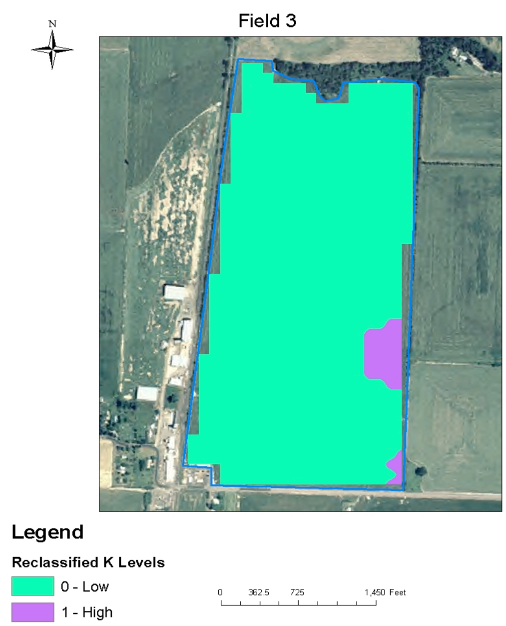
a) Soil K map



b) 2003 yield map.

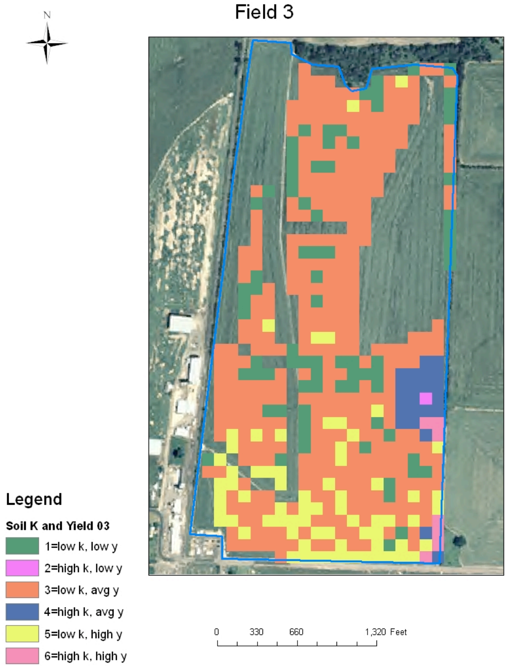


c) Reclassified 2003 yield map

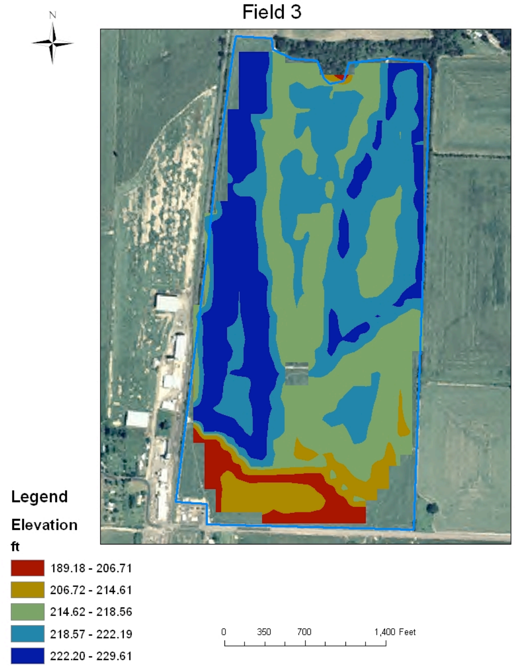


d) Reclassified soil K map

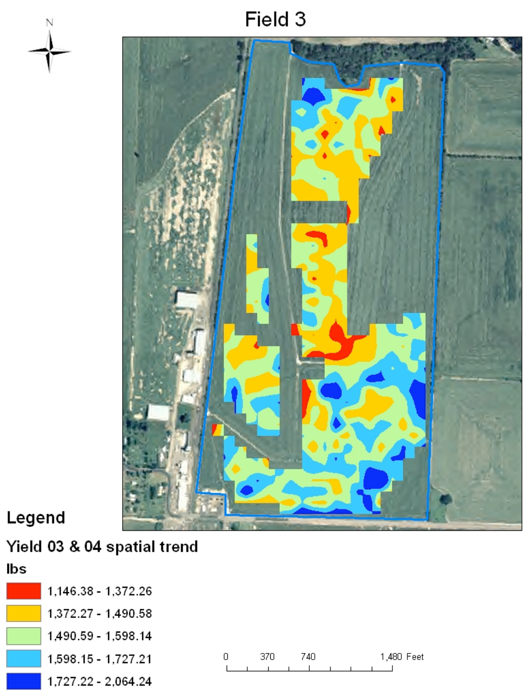
Figure 3.7. Field 3 ArcGIS 9.0 maps: a) Soil K, b) 2003 yield, c) Reclassified 2003 yield, d) Reclassified soil K, e) Soil K - 2003 yield combination, f) Elevation, g) Spatial trend.



e) Soil K and 2003 yield combination map



f) Elevation map



g) Spatial trend 2003 – 2004 yield map

Figure 3.7 (Continued). Field 3 ArcGIS 9.0 maps: a) Soil K, b) 2003 yield, c) Reclassified 2003 yield, d) Reclassified soil K, e) Soil K-2003 yield combination, f) Elevation, g) Spatial trend.

Field 3 soil nutrients and yields were not distributed uniformly over the entire field, as indicated by the example maps soil K (a), 2003 yield (b), reclassified soil K (c), and reclassified 2003 yield (d). There were specific areas of high, average, and low yields while like in Field 2, soil K levels were found to be low over almost the entire area sampled. The soil K and 2003 yield combination map indicated that there were different combinations of high, average, and low yields with low levels of K. There were only small areas of low yields relative to the low levels of soil K. This indicates that soil K probably was not the most important factor controlling 2003 yields within this field. The reclassified soil K map (d) indicated that a uniform application of soil K might be more appropriate than a prescription application of K due to the low level of K over almost the entire field. Finally, the elevation map (f) for Field 3 indicated that a small change in elevation from the eastern side of the field to the western side. The spatial trend 2003 to 2004 yield map (g) indicated that over the last two years of yield collection, the highest yields were recorded in the southern end of the field where the elevation was the lowest.

Creating the yield, soil nutrient, elevation, reclassification, and soil-yield combination maps was a lengthy and time-consuming process involving intimate knowledge of the ArcGIS 9.0 software. Creating these maps was a multiple step process involving many mouse clicks and memorization of the tools and process used. To create accurate maps, a sound understanding of the data and operations used, such as thematic classification and physical reclassification, was needed.

3.1.5 Discussion

3.1.5.a Regression Analysis

All the growers who participated in the workshops were interested in using GIS to determine if relationships exist between soil nutrients and yields in their fields. They wanted to know if there is a statistical way to look for relationships, as visual inspection is commonly used. Only a few consultants currently use statistical analysis to investigate soil and yield relationships beyond visual map inspection.

Checking for relationships between soil nutrients and yield is often the first place a grower looks in trying to improve yields because adding fertilizer or lime is a normal management practice. However, soil nutrients may not be the limiting factor. Yield variability can be traced to other factors such as pests and weeds, climate and amount of water during the growing season, drainage during the wet winter months, and previous management practices such as removing straw after seed collection. Still, soil nutrients need to be monitored. Finding that soil nutrients are not the cause of yield variability gives the grower insight to look at other factors.

In the ideal situation growers would be able to do all their tasks in one program, but for some tasks ArcGIS 9.0 had limitations. It was thought the process of linear regression between yield, soil nutrients and elevations could be automated easily in ArcGIS 9.0. However, this ended up being so difficult that the data were compiled manually and linear regressions were completed in Excel.

3.1.5.b ArcGIS 9.0 Maps

The ArcGIS 9.0 maps created in this project provided the key cooperating grower with valuable spatial field information. With these maps the grower can note areas of high and low yield, soil nutrients, and elevations of the field. Yield spatial trend maps can be helpful in identifying areas of a field that are constantly higher or lower yielding. With more years of yield data, a better picture of average yield levels can be obtained, and this can be used to determine if climatic variables may have influenced yields. With the addition of a background image, the grower can see if low yield corresponds to road, swale, intermittent stream, or heavily non-crop vegetated areas of the field. The spatial mapping of yields, soil nutrients, and soil types provides a grower with a spatial view of their fields that can be coupled with on the ground knowledge to document potential field problems including weed and pest infestations.

The methods for creating maps in ArcGIS 9.0 are flexible in that growers can adjust cell sizes for yield interpolation, as well as define different groups of yield (below average, average, and above average) based on their own field knowledge. Symbolizing the yield and soil maps is flexible in that growers can choose to break up the map based on their own ideas of how the data should be separated. This can allow growers to dig deeper into their data and obtain a better understanding for field phenomena.

As noted in the Results Section, yield, soil nutrient, reclassified, and combination maps in ArcGIS 9.0 were not easy to create. Map creation involved multiple steps and is probably too complicated for most growers, with limited time to accomplish on their own. However, these methods are similar to the methods incorporated automatically in many agricultural GIS programs for making yield and soil nutrient maps. If growers are familiar with how the maps are created, this might give them a better understanding of the limitations of the maps as well as what is being done within the more automatic programs to create them.

The mapping of yield and soil nutrients demonstrates the problems of data collection and availability in agriculture. Full field yield collection is often not possible because yield monitors and or combines break down. The timing of seed harvest is crucial and cannot be stopped because a yield monitor is broken. Unlike yield, soil sample points are usually only collected on a 2.5 acre grid instead of all over the field due to the expense of the soil tests. This creates a difference in spatial resolution between yield data, which are collected every five feet, and soil points, which are collected every 350 ft. Finally, imagery is usually too expensive for a grower to collect over the whole growing season, so they will often only have one image it is usually not near-infrared. As technology improves and becomes cheaper, the problems of agricultural data collection should lessen and provide growers with better quality data.

3.2 Prescription Mapping Overview and Methods

Prescription maps are used in guiding VRT equipment in the variable-rate application of crop inputs such as lime and fertilizers. Soil nutrient tests can be used for the creation of fertilizer prescription maps. One grower suggested experimenting with using yield data for estimating where PGR applications might be successful.

However, yield information is from the previous growing season, collected six months before the PGR should be applied, and it does not give current information about how crop density may be changing. Remotely sensed imagery may provide a solution as it can be used to estimate crop growth and density during the growing season (Jayroe et al. 2005).

Along with GIS and GPS technologies, remote sensing has become increasingly important in site-specific management of agricultural crops in the Midwest, but its use is only experimental in grass seed. A remote sensing device measures energy reflected from a specific object and records it in different formats, depending upon the sensor being used (Fraizer et al. 1997). Remotely sensed imagery can be incorporated in GIS to provide background layers for farm mapping and aid in the assessment of crop health and density within a field. The classification of remotely sensed imagery into vegetation indices can provide information about the amount of biomass present as well as crop yields (Shanahan et al. 2001; Senay et al. 1998).

Methods were devised for using ArcGIS 9.0 to create both fertilizer and PGR prescription maps. These methods can be incorporated into a future set of GIS lessons to provide growers with the ability to create their own prescription maps. Soil nutrient tests and the OSU Extension Service fertilizer guide for perennial ryegrass (Hart et al. 2005) were used to devise a method for creating fertilizer prescription maps in GIS for Fields 1 – 3. Remotely sensed images were collected for Fields 4 – 6 located in Polk County and used during the creation of GIS prescription maps for PGR chemicals.

3.2.1 Data

The soil nutrient K was the example nutrient used in the GIS method devised for creating prescription fertilizer maps in ArcGIS 9.0. The kriged K soil nutrient grids for Fields 1, 2, and 3, described in the previous section, were used for creating K soil nutrient prescription maps for each field.

Unfortunately, the grower did not have imagery for Fields 1 – 3. Therefore Fields 4 – 6 and yield data were used for creating PGR prescription maps. As described in the previous section, 2004 yield data were kriged using a cell size of 60 x 60 ft to create yield maps for Fields 4, 5, and 6.

Remotely sensed aerial photography was collected on April 22, 2005 for Fields 4, 5, and 6. This imagery had a resolution of 2.5 meters and includes the near infrared (Band 1), red (Band 2), blue (Band 3), and green (Band 4) bands. The imagery was registered to the WGS 84 geographic coordinate system and is shown in Appendix J. The grower, through his consulting company, provided the imagery.

3.2.2 Soil Nutrient Prescription Mapping

The following method was devised for using ArcGIS 9.0 SA to reclassify soil nutrients into new fertilizer prescription maps. Following the OSU Extension fertilizer guide for perennial ryegrass (FG 63 ?), Hart et al. (2005), prescriptions for K were made according to the current level of field nutrients (Table 3.5).

Table 3.5. Potassium Application Levels For Existing Field Nutrients.

Existing Field K Levels (ppm)	Application Rate of K (lbs/acre)
0 – 50	200
50 – 100	150
100 – 150	75
above 150	0

The *Con* conditional statement was used in the SA Raster Calculator to create new grids (ESRI 2004). An example of the Con statement used was: Con(([Potassium]>0 & [Potassium] < 50), 200, ([Potassium] > 50 & [Potassium] < 100), 150, ([Potassium] > 100 & [Potassium] < 150), 75, 0). This example created a new grid where all values falling between 0 and 50 ppm were reassigned to 200 lbs/ac, all values between 50 and 100ppm were reassigned to 150 lbs/ac, all values between 100 and 150ppm were reassigned to 75 lbs/ac, and all other values (all values above 150ppm) were reassigned to 0 lbs/ac. Field K levels above 150 ppm did not need any additional K and were therefore assigned to a value of zero lbs/acre.

After the prescription map grids were created, they were exported, using the SA Convert Raster to Features tool, to shapefile format. The shapefile spatial data format was chosen as some variable rate equipment can read this format for prescription applications.

3.2.3 PGR Prescription Mapping

PGR applications have been used to increase yields in cool season grass seed crops by reducing plant stem size for optimal seed production (Silberstein et al. 2000). OSU has been researching the effect of PGR application on grass seed crops since

1997 and has found it to not only increase grass seed yields but to also be environmentally safe, breaking down rapidly in the soil and not having a lasting affect on future crops (Gingrich and Mellbye 2000). Growers want to be able to create prescription maps for PGR applications to save money, as PGR chemicals are very expensive - one pint of PGR can cost up to $22 per acre.

3.2.3.a PGR Prescription Maps Based on Yield

Yield levels for variable PGR application were determined by consultation with an OSU Extension seed researcher (pers. comm. Silberstein 2005). Higher levels of PGR were assigned to high yield areas, as the expected increase in yield and financial return is greater from higher yielding areas. PGR was not assigned to low levels of yield due to the lack of cost recovery from applying the chemical on low yielding areas. Using the SA Reclassify tool, yield maps were reclassified to new grids. Yields less than 1500 lbs were assigned to receive one pint of PGR while yields above 1500 lbs were assigned to receive two pints of PGR (Table 3.6). A grower can change the level of yield used in assigning PGR application levels at any time.

. Table 3.6. PGR Application Levels

Yield (lbs)	PGR (pt)
0 - 500	0.0
500 - 1500	1.0
Above 1500	2.0

3.2.3.b PGR Prescription Maps Based on NDVI

Remotely sensed imagery and imagery vegetation classification techniques, such as the Normalized Difference Vegetation Index (NDVI), can provide an estimate of vegetation health and a way to monitor changes in vegetation over time (Roel and Plant 2004). NDVI classification of remotely sensed imagery can aid in the determination of crop yields can improve yield maps (Dobermann and Ping 2004). NDVI is used as a way to enhance remotely sensed imagery to get the best view of biomass or crop canopy. For more information on NDVI, see Weier and Herring (2001).

Remotely sensed imagery is made up of different bands that record reflectance from different wavelengths of energy. Bands can record reflectance from visible light to thermal radiation. NDVI is an image calculation in which the difference of two bands is divided by their sums (Jayroe et al. 2005). NDVI can be derived from the Near IR and Red bands as the reflectance of healthy and non-healthy vegetation can be distinguished with these bands. Healthy vegetation has higher reflectance in the NIR band and low reflectance in the red band thus giving healthy vegetation a high index. Bare soil has a low reflectance in the NIR band and a high reflectance in the red bad producing a low and sometimes negative NDVI index used to distinguish between bare soil and vegetation. In this study the red band (Band 2) and the near-infrared band (Band 1) were used to calculate NDVI = [(Band 1)-(Band 2)]/[(Band 1)+(Band 2)].

In the SA Raster Calculator, the *Float* statement in addition to raster math was used to calculate the NDVI index for Fields 4 – 6. The *Float* statement specifies that calculations were completed with non-integer data, instead of grids being rounded to integer data, which is the default method of the SA Raster Calculator (ESRI 2004). An example of the Raster Calculator calculation used to create NDVI index grids from the four band aerial imagery was: (Float(Band1 – Band2)) / (Float(Band1 + Band2)). The output NDVI grids had values ranging from –1 to 1 with negative and zero values indicating bare soil and values closer to 1 indicating dense vegetation.

The NDVI maps were then projected, using the Project Raster tool in the ArcToolbox Raster Projection toolset, into NAD 1983 State Plane coordinates, Oregon North Zone (feet). This was done in order to resample the NDVI index grids from a pixel size of 2.5 meters to 60 feet pixels to accommodate the width of agricultural sprayer equipment. The projected NDVI index maps were then reclassified, using the SA Reclassify Tool, according to each maps SD into three classes of 0 = no PGR, 1 = 1pt of PGR, and 2 = 2 pts of PGR. Table 3.7 lists the NDVI cutoff values used for Fields 4 – 6 to specify levels of PGR application. Field 6 was only assigned two levels of PGR instead of three because the field was uniform in NDVI index and therefore assumed uniform in biomass. The raster PGR application maps were then converted to shapefile using the SA Convert to Features tool as mentioned in the prior section.

Table 3.7. NDVI cutoff values for Fields 4 – 6 used in PGR application map creation.

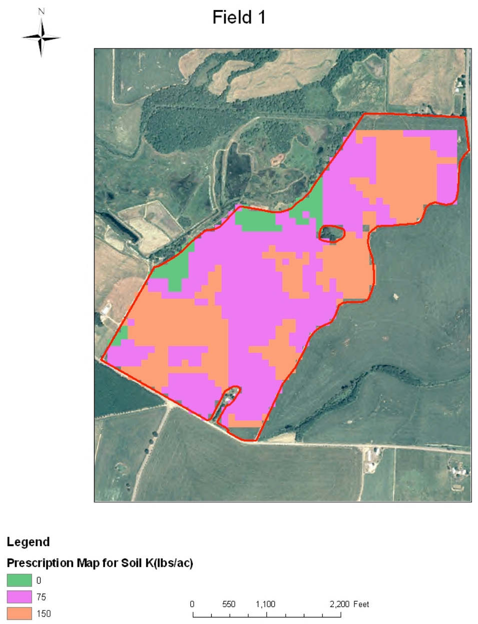
Field	No PGR	1 pt PGR	2 pts PGR
4	-0.5 to 0.34	0.35 to 0.40	Above 0.40
5	0.5 to 0.36	0.37 to 0.45	Above 0.45
6	-0.5 to 0.42	Above 0.42	NA

It was proposed that both yield and NDVI index maps could be used to create PGR prescription maps for Fields 4 – 6. First, the NDVI maps were rescaled in SA to a cell size of 60ft to match the resolution of the yield data. The ArcToolbox Band Statistics Collection tool, in the SA Tools Multivariate toolbox, was used to see if there was any correlation between 2004 yield and 2005 NDVI index maps of the same field. No correlation between yield and NDVI was found; therefore, the investigation of methods for making prescription maps with yield and NDVI was not pursued any further.

3.2.4 Results

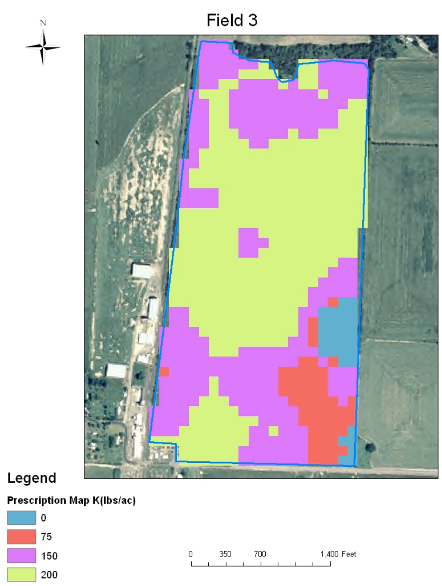
3.3.4.a Soil Nutrient Prescription Maps

ArcGIS 9.0 fertilizer prescription maps were created to demonstrate how the software could be used to create prescription maps using soil nutrient maps and the OSU Extension fertilizer guide for perennial ryegrass. Based on the OSU Extension fertilizer guide for perennial ryegrass, recommendations for fertilizer K levels were made and assigned to the appropriate areas of the fields. Example fertilizer prescription maps for Fields 1 – 3 can be found in Figure 3.8. The method of creating prescription maps was found to be flexible, allowing growers to alter the maps as they saw fit.



a) Field 1

b) Field 2



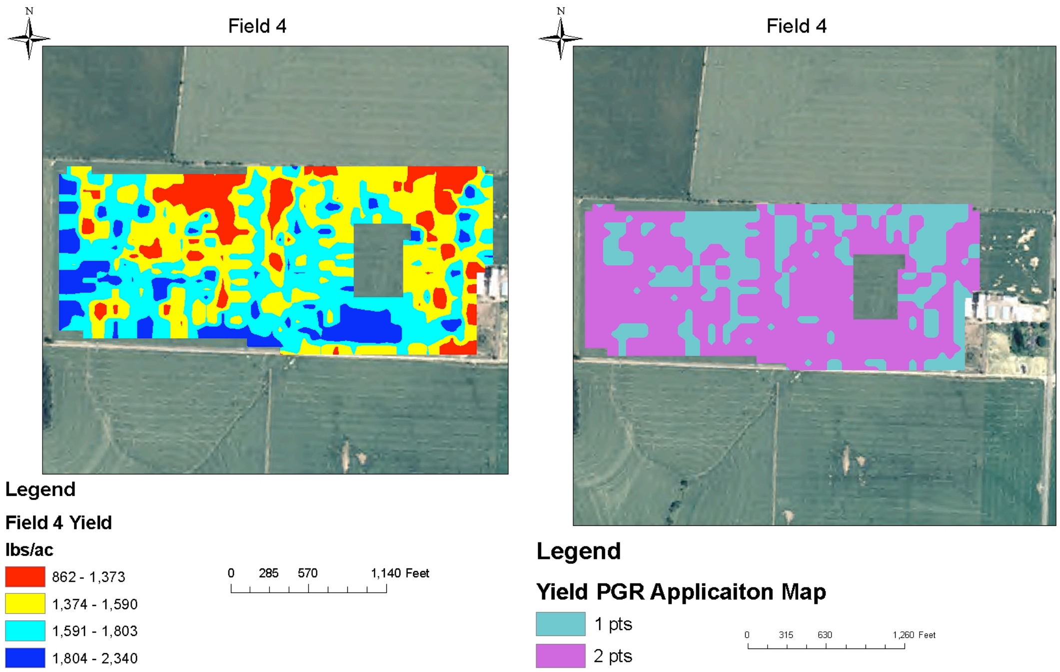
c) Field 3

Figure 3.8. Example soil K prescription maps for a) Field 1, b) Field 2, c) Field 3.

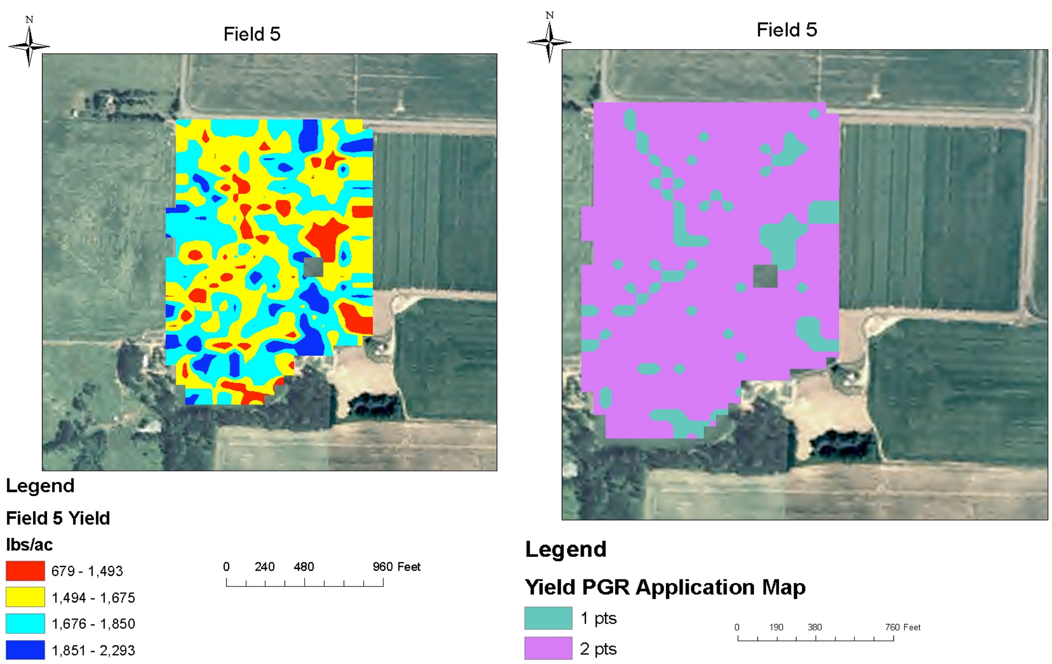
The soil K prescription map (a) for Field 1 showed areas of the field that do not require additional soil K, as the current levels are sufficient. Field 1 had the highest levels of soil K and therefore required the lowest K application rates. Field 2 soil K levels were low over the entire field, which was reflected in the prescription map, indicating that the majority of the field should receive the highest levels of soil K fertilization to bring the soil K up to appropriate levels. In Field 2 (b), the prescription areas of 75lbs/ac were so small they could be combined with the 150lbs/ac rate to divide the field into two levels of K application instead of three. The Field 3 (c) soil K prescription map indicated that the field needed the full spectrum of K application rates from 0lbs/ac to 200lbs/ac displaying a large range of soil K variability across the field.

3.2.4.b PGR Prescription Maps Based on Yield

PGR prescription maps were created in ArcGIS 9.0 to demonstrate how the software could be used to create PGR prescription maps using 2004 yield data. Example 2004 yield-based PGR prescription maps for Fields 4 – 6 can be found in Figure 3.9. The method of creating PGR prescription maps from 2004 yield was found to be flexible allowing growers to alter the maps based on different yield levels or as they see fit.

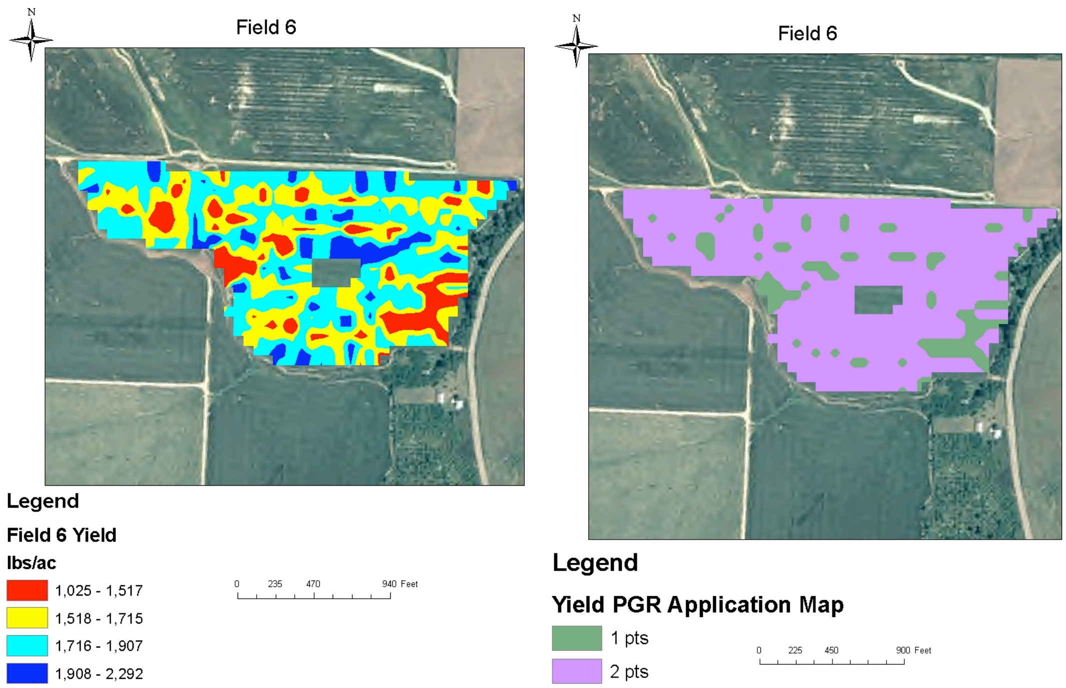


a) Field 4



b) Field 5

Figure 3.9. 2004 yield and PGR prescription maps: a) Field 4, b) Field 5, c) Field 6.



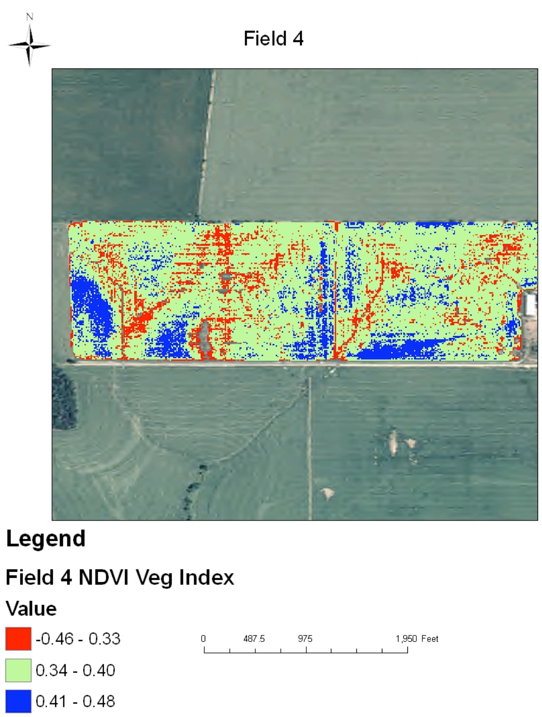
c) Field 6

Figure 3.9 (Continued). 2004 yield and PGR prescription maps: a) Field 4, b) Field 5, c) Field 6.

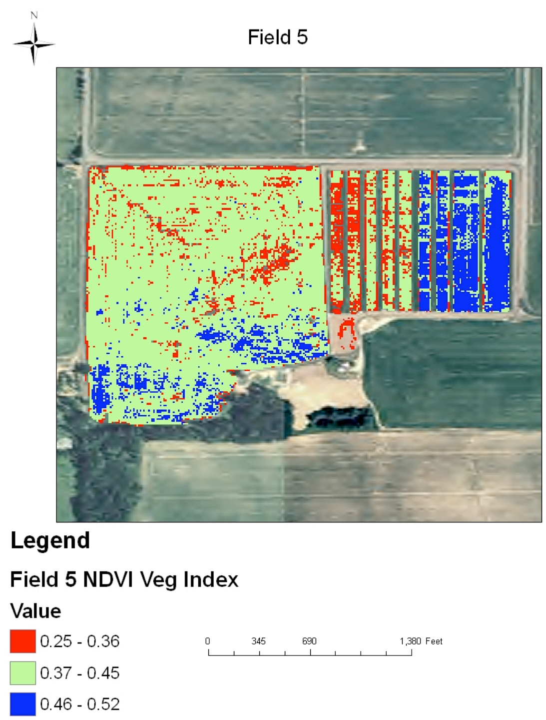
All three prescription maps closely followed the patterns of yield in the yield maps. The majority of the yield recorded was above 1500lbs, therefore two pints of PGR was prescribed for the majority of the area within each field. More areas of yield differences occurred within the Field 4 PGR prescription map (a), compared to the other fields. The Field 5 PGR prescription map (b) displayed sections where lower levels of PGR were required but seem to be patterned around corner paths of yield data collection, which may not be accurate. A grower might have only used the two-pint level of PGR application on Field 5, whereas he or she would have used both the one and two pint levels on Field 4. Similar to Field 5, the Field 6 PGR prescription map (c) also displayed low variability of PGR application areas. A grower might have only used the two-pint level of PGR application on Field 6 due to the low variability of PGR application levels.

3.4.3.c PGR Prescription Maps Based on NDVI

ArcGIS 9.0 PGR prescription maps were created to demonstrate how the software could be used to derive NDVI index maps, using 2005 infrared aerial imagery, as well as create PGR prescription maps from the derived NDVI index data. The derived NDVI index maps for Fields 4 – 6 are shown in Figure 3.10.

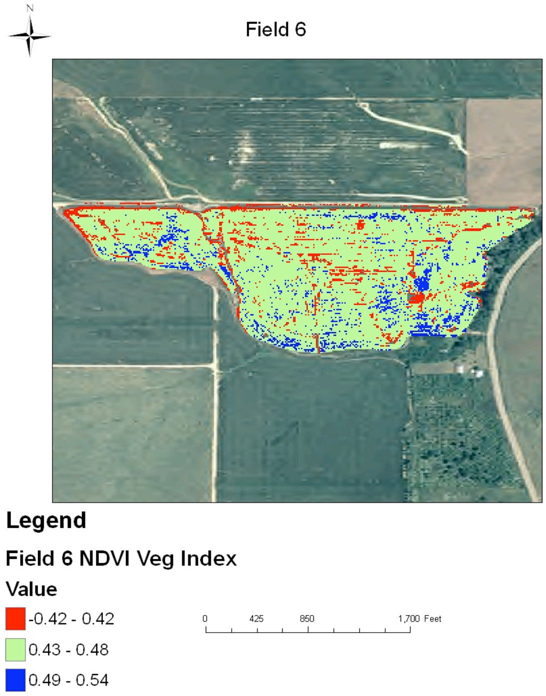


a) Field 4



b) Field 5

Figure 3.10. Derived 2005 NDVI index maps: a) Field 4, b) Field 5, c) Field 6.

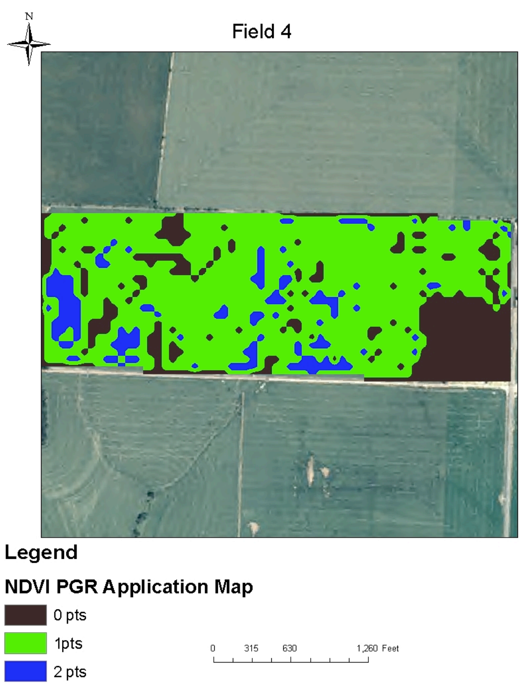


c) Field 6

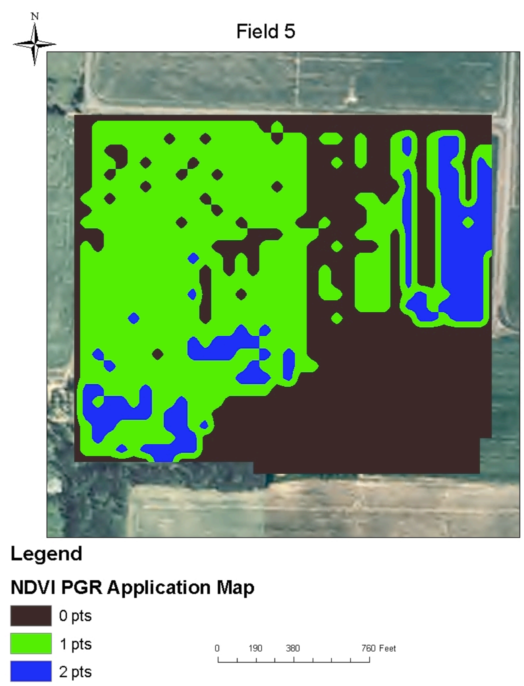
Figure 3.10 (Continued). Derived 2005 NDVI index maps: a) Field 4, b) Field 5, c) Field 6.

The NDVI map for Field 4 (a) displayed the areas that contained bare soil, (no color), high crop density, (blue), average density areas, (green), and low density areas, (red). The high crop density areas were located in the southern part of the field while the low crop density areas followed the patterns of roads and the water or swale areas running across the field. Within the NDVI map for Field 5 (b), the crop-planting pattern can be seen. The north to south diagonal low crop density pattern is similar to that of the low PGR application rate in the PGR application map based on 2004 yield. The southern end of Field 5 contained the highest crop densities. Within the NDVI map for Field 6 (c), bare soil and low-density areas followed the patterns of roads and swale areas with the field. Field 6 NDVI displayed a more uniform pattern of average crop density than Fields 4 and 5. The accuracy of the derived NDVI indexes for all fields was not tested. No ground truth data for the images were collected during this study. Therefore, growers should use discretion when evaluating the NDVI and PGR prescription application results.

From the NDVI index maps, PGR prescription maps were created to display areas where different rates of PGR chemicals should be applied. Example NDVI based PGR prescription maps for Fields 4 – 6 are shown in Figure 3.11. The method of creating PGR prescription maps from NDVI was found to be flexible, allowing growers to alter the maps based on different NDVI index levels.

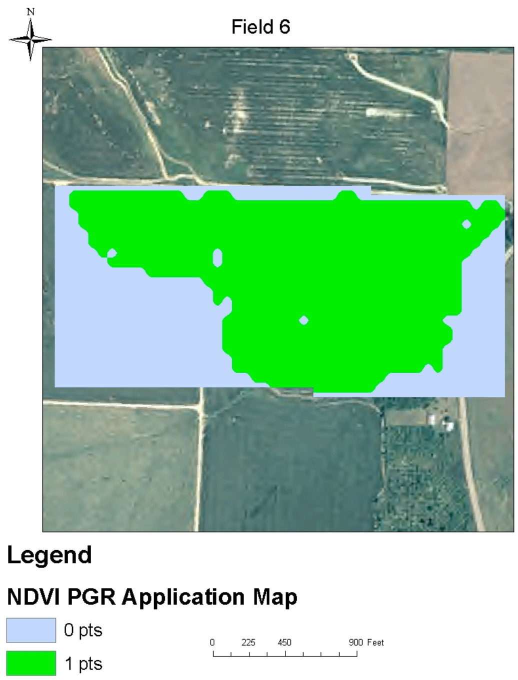


a) Field 4



b) Field 5

Figure 3.11. PGR Prescription Maps from NDVI index: a) Field 4, b) Field 5, c) Field 6.



c) Field 6

Figure 3.11 (Continued). PGR Prescription Maps from NDVI index: a) Field 4, b) Field 5, c) Field 6.

The NDVI PGR prescription maps for Field 4 (a) and Field 5 (b) displayed three levels of PGR application rates. These rates included zero pints for all those bare soil and low density areas represented by black, one pint for all those average density areas represented by green, and a rate of two pints for all those high density areas represented by blue. Both of these fields have distinct high and low density areas; therefore variable rate application of PGR was applicable for these fields. The NDVI PGR prescription map for Field 6 (c) only displayed two levels of PGR application rate. The PGR rates were zero pints for all those areas of bare soil and low density represented by blue and one pint for all those areas of average density represented by green. Due to the overall uniformity of the average NDVI index throughout Field 6, only one rate of PGR was assigned for this field. Varying the rate of application requires an additional cost and might not be necessarily used on a uniform field; therefore only one rate of PGR was assigned to Field 6.

As demonstrated by Table 3.8, there was no correlation between 2004 yield and NDVI index derived from 2005 aerial near-infrared imagery. Therefore, yield and NDVI were not combined to create prescription maps for PGR.

Table 3.8. 2004 Yield and 2005 NDVI Correlations.

Field	Yield and NDVI Correlation
4	0.29439
5	-0.00957
6	-0.12273

Creating the PGR prescription maps was a lengthy and time-consuming process involving intimate knowledge of the ArcGIS 9.0 software. Creating prescription maps was a multiple step process involving many mouse clicks and memorization of the tools and process used. It was observed that in order to create accurate maps, a sound understanding of the data and operations used, such as reclassification and NDVI index calculations, was needed.

3.2.5 Discussion

Like the methods for creating yield and soil maps in ArcGIS 9.0, the methods used for making soil nutrient and PGR prescription maps based on yield are flexible. A grower can easily adjust how the fertilizer and yield application levels are assigned when making the maps. Once soil nutrient and yield maps are created, prescription maps are relatively easy to create in ArcGIS 9.0, as they only require the reclassification of the soil nutrient and yield map. After looking at the yield and or soil data maps, a grower can decide if only one rate of fertilizer or PGR application would be more effective due to a lack of spatial variability in yield or soil nutrients.

If growers have access to near-infrared imagery, they can use it to create NDVI index maps that provide valuable crop growth density and potential yield information. In previous studies with corn and soybeans, NDVI index data were highly correlated with yield, however no studies in NDVI and yield correlation for grass seed exist. Growers can use NDVI maps to predict where future yields may be high or low, as well as look for weed and pest infestations. The grass seed crop density information provided by NDVI index maps can also help a grower to decide where PGR application would be most valuable, as PGR is applied to more dense crop areas.

Although the NDVI index can provide valuable crop density and potential yield information, NDVI index maps were not easy to create. Obtaining near infrared imagery can be difficult and if it is not taken at the appropriate time it cannot be used. Creating NDVI index and prescription maps was complicated and involved multiple steps.

It was suggested that both yield and NDVI data could be used to make PGR prescription maps. The relationship between 2004 yield and 2005 NDVI data was analyzed for correlation. However, no correlation was found. This indicated that there might be a different crop growth pattern emerging from the previous year’s yield collection. Therefore, yield and NDVI was not used together to create prescription maps. NDVI probably provides the best estimate of crop density, since it is the most current, for use in PGR prescriptions.

4. Agricultural GIS Software Comparisons

4.1 Overview and Methods

The fact that ArcGIS 9.0 was so difficult to use prompted the author to investigate other GIS software for precision agriculture to see if other software could do the tasks growers want easier or better than ArcGIS 9.0. One barrier to precision agriculture technology adoption is the grower's lack of information about advantages and disadvantages of different equipment and techniques of precision agriculture technologies (Khanna 2001; Khanna et al. 1999; Wiebold et al. 1999). Currently, for grass seed growers in the Willamette Valley, precision agriculture consultants and dealers are the only resource for information about precision agriculture technologies. Providing information about agricultural GIS software packages available to growers can help them in making informed decisions about the technology they would like to invest in, which is important as technology can be a very expensive initial investment. Like any consumer, growers would like unbiased information about the different products available so they can make an educated decision and get the most for their money.

A task-based comparison of five precision agriculture GIS software packages was performed to provide growers with information about the advantages and disadvantages of each. The five GIS software packages chosen are commonly used agricultural GIS programs that might be useable in grass seed crop management. Growers can use this information to help them choose precision agriculture software that will best fit their farming operations.

Several information gathering and function questions were formulated to compare the five different precision agriculture GIS software packages (Table 4.1). Details on the cost, technical support, data types that can be imported or exported, yield monitor data compatibility, GIS analysis, report and chart creation, map printing, querying, symbolizing, and editing abilities were recorded in Excel.

Table 4.1. Precision Agriculture GIS Software Packages Compared.

ESRI	***Red Hen Systems Inc.***	***AgLeader***	***FarmWorks***	***MapShots***
ArcGIS 9.0	FarmHMS	SMS Basic	Farm Trac+	EASi Suite
Spatial Analyst	MapCalc	SMS Advanced	Farm Site	IntelliCalc
			Site Pro	

Several resources were used to compare the software packages, including books, websites, and help menus from the software itself: Nusbaum ed. (2002), Red Hen Farming Systems (2004), Ag Leader Technology (2005), and MapShots (2005).

4.2 Results

The agricultural GIS software comparisons are found in Appendix K. The GIS software programs were placed into either the beginner or advanced GIS category based on the tasks they could perform and the difficulty of performing these tasks. The comparisons were based on ArcGIS 9.0.

Besides the difficulty of accomplishing many tasks in ArcGIS 9.0, another disadvantage is that combine yield data must first be converted in another program to shapefile format before it can be used in ArcGIS 9.0. An important advantage is that ArcGIS is widely used by government agencies involved with agriculture. ESRI is a big company and will continue to support their software into the future. The Spatial Analyst extension is required for creating yield and calculated prescription application maps. ArcGIS 9.0 is one of the most expensive packages, costing $4000 to purchase both the basic mapping and Spatial Analyst extension. Technical website support is free while phone support costs money after the first year of free help.

Red Hen Systems FarmHMS and MapCalc Professional is an advanced software package. Unilke ArcGIS 9.0, FarmHMS can work with many brands of yield monitor card data and can produce a simple yield map. However, it has only basic mapping and no GIS capabilities. Yield data from a combine must first be converted in FarmHMS or another program before it can be used in the MapCalc Professional GIS program to create better yield maps. Calculated prescription application maps and statistical analysis such as correlations, can be performed in MapCalc Professional. Even though MapCalc Professional is more tailored to agriculture then ArcGIS 9.0, it is still complicated and somewhat difficult to learn. MapCalc Professional can import vector data, but it can only perform calculations on raster data. FarmHMS and MapCalc Professional cost approximately $1200. Technical website and phone support are currently free.

MapShots EASi Suite and the InteliCalc add-in extension is also an advanced GIS software package. EASi Suite integrates automated record keeping and advanced reporting capabilities with basic GIS mapping. The InteliCalc extension, which is similar to the ArcGIS 9.0 Spatial Analyst extension, is needed to create calculated prescription application maps and perform GIS analyses. The farm version of EASi Suite and InteliCalc are approximately $1440, while the consultant version is considerably more. Technical website and phone support are currently free.

The first beginning GIS software program investigated was FarmWorks FarmTrac +, FarmSite, and SitePro. FarmWorks provides an integrated package of nine different programs for total farm management including software for mapping in the field as well as farm record keeping and finances. These programs were easier to use and more user friendly than the more advanced programs. FarmTrac + provide basic mapping as well as farm record keeping that can be used for field planning. FarmTrac + has no analytical GIS capabilities. FarmSite is the next step up from FarmTrac + and provides more mapping functionality plus the ability to add different layers and use yield monitor data to make yield maps. It allows the manual, but not calculated, creation of prescription application maps. SitePro has the same capabilities as FarmSite with the additional ability to complete simple statistics and handle more than one farmers' data. SitePro also includes FarmSite Mate to allow creation of data in the field. FarmTrac + and FarmSite were priced together at $600 while SitePro costs $1000. Technical phone support can be purchased for $150 per year.

Another beginning GIS software program was Ag Leader SMS Basic and SMS Advanced. Both SMS Basic and Advanced provide basic GIS yield mapping, manual prescription map creation, some field record keeping, and field planning. These programs were also easier to learn and to use than the advanced GIS programs and provide an introduction to GIS for beginning users. SMS Basic costs $600 while SMS Advanced costs $1500. Technical website and phone support are free.

4.3 Discussion

Growers want to be able to choose the best program for storing and handling all of their GIS data, rather than buying several for different uses. When asked about what other GIS software programs growers would use besides ArcGIS 9.0, many could not answer the question because they did not know what other programs are available. Five of the most common agricultural GIS software programs were investigated and compared to provide growers with information about potential GIS software programs for their farms.

All of the software programs have strengths and weaknesses. There is not one perfect software program. For example, FarmHMS was very efficient at importing yield data and making simple yield maps but it could not make prescription maps. There is a definite learning curve for all investigated GIS software programs. Some of the programs are easier to learn and have more automated tasks than others, but lack the analysis power that a more complicated program has.

5. Conclusions

Progressive grass seed growers are very interested in applying precision agriculture GIS and GPS technologies on their farms. The growers involved in this research believe that GIS has the potential to help them make management decisions that can improve yields as well as reduce input use. In this research, grower input was essential in the identification of the GIS tasks that grass seed growers want to be able to accomplish. These became the basis for the educational materials and the training that was developed. The ArcGIS 9.0 lessons and workshops created in this research were found to increase the participants understanding of GIS technology. Most of the growers involved in this research plan to continue trying to incorporate precision agriculture practices into the management of the farms with either ArcGIS 9.0 and other agricultural GIS software programs.

The participating growers identified some of the same barriers to GIS technology adoption mentioned in the literature: 1) grower lack of time to work with the technology, 2) costs of the technology, 3) difficult learning curve of the technology, 4) lack of educational materials and training opportunities on the technology, and 5) lack of knowledge about financial returns from investing in the technology as currently precision management is not yet profitable in grass seed production. Additional barriers identified by the author during the course of the research include: 1) interpretation of data is still at the experimental level in grass seed, and 2) difficulty of obtaining timely data.

Further research in precision agriculture technologies is needed to help grass seed growers of the Willamette Valley move past these GIS technology adoption barriers. Rresearch topics include: 1) training opportunities for growers, 2) information on software and equipment, 3) standardization of software and data, 4) cheap access to accurate and timely data, 5) data interpretation for prescription applications, and 6) financial returns.

Although some precision agriculture training opportunities for growers currently exist, most are concentrated in the Midwest. Oregon lacks precision agriculture training opportunities for growers. Time and money should be spent in developing and presenting training opportunities to help further develop precision applications and training for growers.

Willamette Valley growers lack unbiased information on precision agriculture software and equipment. Research should concentrate on making an unbiased consumer guide for precision agriculture equipment so growers can compare equipment benefits and use this information to decide which technologies to pursue.

Currently, there is no standardization of precision agriculture software and data (Wiebold et al. 1999). For example, combine yield monitors collect data in different formats depending on the manufacturer. Although most agriculture GIS programs are beginning to be able to work with a wider range of data formats, it would be easier for growers and consultants if all precision agriculture data came in a file format that would allow growers and consultants to work with one GIS software program. Furthermore, if agricultural GIS software can be made user-friendly by automating the tasks a grower would like to accomplish, this would help in adoption of the technology. Currently, most GIS programs are difficult for growers to use (Wiebold et al. 1999).

Cheap and easy access to accurate and timely data for growers is needed. Currently, only a few Willamette Valley growers utilize aerial or satellite imagery due to its high expense. Ventures such as cooperative imagery purchasing from or with government agencies might help to alleviate this expense. Equipment such as yield monitors and calibration tools, need to be more reliable to ensure data collection occurs accurately and at all times. Better tools for processing data, such as yield data correction, are needed (Blackmore and Moore 1999). Finding simple methods for investigating relationships between various nutrients and yield would be valuable for growers as well. Finally, incorporating near infrared satellite imagery over the entire growing season might be useful in determining causes of yield variability.

Once growers accumulate spatial farm data, they usually need help interpreting the data. Research is needed to develop methods or systems that enable farmers to translate all of their spatial farm data into application decisions (Khanna et al. 1999). For example, ground-truth data to verify that prescription maps improve yield are needed. Site-specific farming will become more profitable if consultants and growers can use their spatial farm data to make better management decisions (Swinton and Lowenberg-DeBoer 1998). Furthermore, research in crops besides corn, soybeans, and cotton is needed if precision agriculture applications are to become widespread.

The largest barrier to precision agriculture adoption is the cost of the technologies involved. Currently there is little information on the role precision agriculture technologies play in increasing grass seed profitability. Providing growers with research-based information on financial returns in precision agriculture will help make the decision to invest in precision agriculture technologies easier for growers (Wiebold et al. 1999). When it becomes clear to growers that a technology can bring reliable financial returns, the adoption will quickly occur.

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APPENDICIES

Appendices A – K

Appendix CD

A SUPPLEMENT FOR THE THESIS OF

Keldah Elizabeth Hedstrom for the degree of
Master of Science in
Geography presented on June 6, 2005
Title: Introducing Geographic Information Systems to Grass Seed Growers in the Willamette Valley of Oregon

This compact disc contains all of the appendices in this thesis in Microsoft Word document (.doc) and Power Point (.ppt) files. This compact disc also contains all the data required for the agricultural GIS lessons in Appendix B (located in the AgGISdata folder).

List of Appendices: