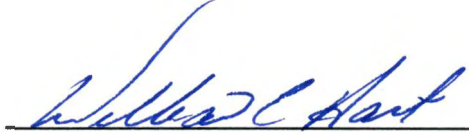


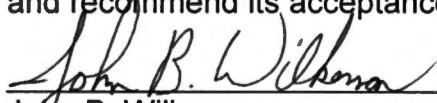
To the Graduate Council:

I am submitting herewith a thesis written by Nathan D. Sewell entitled "Data Acquisition System for Evaluating Spatial Accuracy of Selective-Type Sprayers." I have examined the final paper copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Biosystems Engineering Technology.

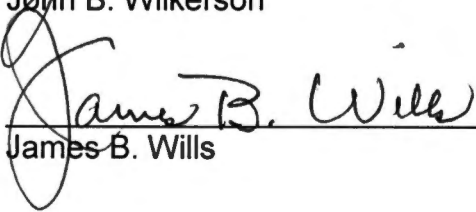


William E. Hart, Major Professor

We have read this thesis
and recommend its acceptance:

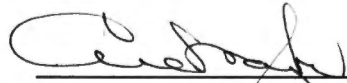


John B. Wilkerson



James B. Wills

Accepted for the Council:



Vice Provost and Dean of
Graduate Studies

**Data Acquisition System for Evaluating Spatial Accuracy of
Selective-Type Sprayers**

**A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville**

**Nathan Dwayne Sewell
May 2002**

Thesis
2002
.549

ACKNOWLEDGEMENTS

There are many people to whom I am grateful for making my time at The University of Tennessee enjoyable and rewarding. First, I would like to thank the Department of Agricultural and Biosystems Engineering for admitting me to further my education in this field of study. In addition, I would like to thank my major professor Dr. William E. Hart for providing assistance and guidance throughout my course of studies.

I would also like to thank the other members on my graduate committee, Dr. John B. Wilkerson and Mr. James B. Wills, both from the Department of Agricultural and Biosystems Engineering. They provided additional assistance and guidance through their experience and knowledge relating to my research. Also included in the list of recognition are several staff members from the department. Henry Moody and David Smith supplied electronic assistance in developing and conducting my research, while Craig Wagoner helped in the design and fabrication of crucial components.

Finally, but most importantly, I would like to thank my family for supporting my efforts to further my education. I would also like to thank my friends, who are also like family, for their support and encouragement throughout the duration. Without these people and their impacts on my life, this quest would have been extremely difficult.

ABSTRACT

The purpose of this research was to test and evaluate a data acquisition system (DAS) that could record a real-time discrete (on/off) event and geo-reference that event with a GPS coordinate. For this research, two selective-type sprayers were used as the site-specific input. The objectives of this experiment were to geo-reference the discrete on/off signal from these sprayers with GPS, generate an application map for the sprayer systems, and compare these application maps to known vegetative coverage.

To accomplish these goals the selective-type sprayers, Detectspray and Weedseeker, were mounted on a three-point hitch sprayer equipped with a 55-gallon tank and a PTO driven 6-roller pump. An interface composed of opto-isolators was designed to isolate the sprayer systems supply voltage from the DAS, and to convert the +12-Vdc analog valve supply voltage to a digital +5-Vdc signal for the DAS. A Trimble AgGPS 132 receiver with differential corrections provided the DGPS signal for these studies.

To field test the system two experiments were performed. The first field test was conducted with a known vegetation/soil pattern setup using dense 15-ft. wide soybean rows with 30 ft. of bare soil between. Two speeds, 2.5 and 5.8 mph, were used to evaluate the affects of speed on the system. In addition, travel direction was oriented at a 45° angle to the orientation of the rows to activate and record each individual nozzle. The second field test was conducted using random vegetation/soil patterns setup with random tillage and random

vegetative growth. Two GPS input frequencies, 1 and 2 Hz, were used to determine if the system could record both rates.

A volumetric evaluation was conducted to verify the recorded data from the DAS to the actual application from the sprayer systems. Artificial activation devices were used to turn the nozzles on and off. The DAS recorded a file while fluid was collected from the solenoid-activated nozzles. A percent of continuous flow was calculated for the nozzles and compared to the percent recorded by the DAS.

Application maps generated for the field tests for both sprayer units display spatial applications of the sprayer systems. These maps were compared to known vegetation maps, and proved to be accurate. The volumetric evaluation verified that values recorded by the DAS were related to the actual application from the sprayer systems. Therefore, the DAS proves to record and reference a real-time discrete site-specific event with a GPS coordinate.

TABLE OF CONTENTS

Chapter	Page
I.	Introduction 1
	1. Background..... 1
	2. Research Objectives..... 2
II.	Review of Literature 3
	1. Site-Specific Field Operations 3
	Herbicide Application 3
	Fertilizer and Lime Application 5
	Seed Application 7
	Tillage 8
	Insecticide Application..... 9
	Plant Growth Regulators10
	2. Data Acquisition Systems10
	3. Selective Sprayer Systems12
	Detectspray13
	Weedseeker14
III.	Materials and Methods15
	1. Data Acquisition Systems15
	Data Recording Unit.....15
	Interface Box.....19
	GPS19
	Data Conversion19
	2. Spraying Systems22
	Selective Sprayer Systems22
	Sprayer and Equipment Mounting.....24
	3. Field Testing28
	Known Vegetation Pattern28
	Random Vegetation Pattern.....31
	4. Volumetric Evaluation38

IV.	Results and Discussion	43
	1. Field Testing.....	43
	Known Vegetation Pattern	43
	Random Vegetation Pattern.....	55
	2. Volumetric Evaluation.....	67
V	Summary and Conclusion.....	73
	1. Summary	73
	2. Conclusions.....	75
	3. Recommendations.....	75
	Bibliography	77
	Appendix.....	80
	Vita.....	90

LIST OF FIGURES

Figure		Page
1.	Schematic illustrating components used to collect site-specific application data.	16
2.	Example file of information recorded by the DRU which included Coordinated Universal Time (UTC), GPS status, GPS coordinates, and nozzle status between each coordinate.	16
3.	DRU used to process and store data for the DAS.	18
4.	Interface box used to sense valve voltages, and convert to optically isolated signal for the DRU for up to 24 nozzles.	20
5.	Example of Information required by the convert program to spatially project sprayer nozzles.	21
6.	Flow chart for the program that converts data logged by the DAS into files that can be used to generate an application map.....	23
7.	Schematic illustrating setup for the Detectspray system which included five units spaced evenly across the 100 in. boom.	25
8.	Schematic illustrating setup for the Weedseeker system which included nine units spaced evenly across the 108 in. boom.	25
9.	The valve driver cartridge (VDC05) replaced the solenoid-controlled nozzle in the Weedseeker units to send a signal to the interface box.	25
10.	Sprayer and roller pump used to mount DAS and selective-type sprayer for field data acquisition.	26
11.	DAS and selective-type sprayer attached to the rear of the original sprayer using a mounting bracket.	26
12.	The known vegetation/soil pattern was setup using 15 ft. wide soybean rows with 30 ft. between these rows to generate a distinct on/off pattern.	29
13.	Random pattern test setup using a combination of random vegetation and tillage to generate the random on/off pattern.....	32

14.	Field layout for the random pattern test consisted of a 50 ft. x 175 ft. plot laid out into 14 blocks.	32
15.	Block layout for the random pattern test consisted of four corner blocks and one numbered center block for geo-referencing.	34
16.	Bucket truck used to collect remote images of the blocks from the random pattern experiment without obstructing the view.	35
17.	The image of block 7 was converted into a vegetation grid based on weed density.	37
18.	Schematic illustrating setup for the volumetric evaluation to artificially activate and record nozzle activity.	39
19.	Flow chart representing the PBASIC program used to send frequency and duty cycle to a SBC during volumetric testing.	41
20.	Circuit used to switch LEDs on and off during the volumetric test.	42
21.	Application map for the Detectspray units traveling 2.5 mph during the known pattern test.	47
22.	Application map for the Weedseeker units traveling 2.5 mph during the known pattern test.	48
23.	Application map for the Detectspray units traveling 5.8 mph during the known pattern test.	50
24.	Application map for the Weedseeker units traveling 5.8 mph during the known pattern test.	51
25.	Soil and weed blocks were constructed to select points from the known pattern test for analysis.	52
26.	Weed pattern was layered back on block 5 from the random pattern test to show accuracy of this grid.	56
27.	Geo-referenced vegetation map from random pattern test displayed true vegetation location.	58

28.	Smoothed vegetation map from random pattern test displayed where the sprayer should have been activated.	58
29.	Detectspray application map for random pattern field test with GPS input set at 1 Hz.	60
30.	Detectspray application map for random pattern field test with GPS input set at 2 Hz.	61
31.	Weedseeker application map for random pattern field test with GPS input set at 1 Hz.	62
32.	Weedseeker application map for random pattern field test with GPS input set at 2 Hz.	63
33.	Soil and vegetation blocks were constructed to select points from the random pattern test for analysis.....	65
34.	Recorded DAS % v/s measured flow % for the volumetric test displays a high linear relationship between the actual % and recorded %.	71
35.	Error for nozzle 1 using the DAS as truth for the volumetric test displays how the nozzle reacted.	72
36.	Error for nozzle 2 using the DAS as truth for the volumetric test displays how the nozzle reacted.	72
A.	QBASIC programming language for convert program CONV6.EXE	81

CHAPTER I

INTRODUCTION

1. Background

Site-specific field operations have grown in popularity over the past ten years. A variety of new technologies make these techniques possible. The most important of these new technologies is the Global Positioning Systems (GPS). Accurate, affordable GPS receivers provide equipment operators the ability to easily measure and record the spatial location of a field operation. As GPS receivers have improved and their cost decreased, the number of farmers using them has risen. In fact, 23.5 percent of 302 young farmers and ranchers surveyed in 2000 by the American Farm Bureau Federation reported using GPS in their operations (Thornton and Kelly, 2000). The ultimate goal of this technology adoption is the ability to tailor field operations site-specifically within fields to maximize profitability. A variety of site-specific field operations are described in the literature.

A datalogger that is able to record a real-time discrete on/off signal and geo-reference the position would be valuable in site-specific farming where applications are spatially discrete. Examples of these applications are selectively applying herbicide to specific weed location, tilling selected areas where soil was compacted by traffic, or replanting areas where vegetation was destroyed. However, a system with this capability is not commercially available. In the

spring of 2000, an effort was initiated at The University of Tennessee to develop a data acquisition system to record and geo-reference these discrete on/off signals.

2. Research Objectives

This research project contains four objectives. The first objective was to test and evaluate a data acquisition system capable of combining GPS coordinates with an on/off signal associated with site-specific farming, specifically, a selective-type sprayer system. The second objective was to generate application maps using data from two selective-type sprayer systems acquired with this data acquisition system. The next objective was to compare these application maps to known vegetative coverage. The final objective was to conduct a volumetric evaluation to verify the data recorded by the DAS.

CHAPTER II

REVIEW OF LITERATURE

1. Site-Specific Field Operations

Site-specific field operations are carried out through various methods. However, these operations can be classified as either occurring in real-time or conducted based on a previously generated application map. Both classifications can be subdivided into a discrete on/off or continuous pattern.

Many site-specific applications/operations could benefit from a DAS capable of spatially referencing the real-time activities. Site-specific methods ranging from pre-planting to post-planting have been tested. Generating an application map for these operations allocate additional resources that may be used to document or improve objectives of these operations.

Herbicide Application

Selective herbicide application is a site-specific farming technique that has received much attention. Brown et al. (2000) used a direct-injection precision sprayer to discretely apply herbicide based on an application map from information collected by field scouts. Herbicide was applied based on intensive weed sampling of a 6- x 6-m grid network in 10-ha fields of corn and soybeans. A prescription map was generated, and overall herbicide use was reduced by as much as 49% relative to a broadcast application.

In another study (Brown and Steckler, 1995), remote sensing was used to collect weed data to generate a map used for discrete application. Image analysis of digitized low altitude aerial photographs was used to generate weed maps for fields of no-till corn. The weed maps were imported into a geographic information system (GIS) and registered to a grid. Image analysis techniques were used to determine whether each grid cell contained enough weeds to warrant spraying. Results indicated a 40% herbicide reduction would have been achieved at these locations if application had occurred.

Herbicide application with selective-type sprayers is a third technique reported, and is based on a real-time discrete pattern. Selective-type sprayers enable individual nozzles to be turned on and off based on the presence of weeds. Ahrens (1994) used the Detectspray, manufactured by Spraying Systems Inc., to apply herbicide on two fallow sites in North Dakota. Results indicated that herbicide savings of 47-88% were possible. In another experiment, Detectspray units reduced herbicide application by 19-60% on fallow fields in the Canadian prairies (Blackshaw et al., 1998). Selective-type sprayers have also been modified to operate in hooded sprayers. Hanks and Beck (1998) used a hooded sprayer incorporating the Weedseeker PhD 612, manufactured by Patchen Inc., to spray row crops. A savings in herbicide ranging from 63-85% was realized.

Herbicides can also be selectively applied based on soil type and percent organic matter (OM%). AL-Gaadi and Ayers (1999) used GPS and GIS to vary herbicide spatially based on soil type and OM%. Using a 4.2-ha field subdivided

into 18.3-m grids, they collected samples from the center of each grid and tested them to determine soil type and OM%. An application rate contour map was derived from these two parameters. Using GPS, a Campbell Scientific 21X datalogger, and a direct nozzle injection field sprayer, it was established that they could apply herbicide with less than 1% error based on the application map.

Shonk et al. (1991) developed a sensor that can determine soil organic matter in real-time, which promises to be useful for a continuous pattern application of soil-applied chemicals. Using red light emitting diodes and photodiodes incorporated into a housing to exclude all ambient light, the photodiodes measured reflected radiant energy from the soil. Correlation between the reflectance and organic matter content for fine and medium textured soils was found to be predictable up to 6% organic matter. Recommendations were to design a microprocessor based control system to interface with chemical applicators.

Fertilizer and Lime Application

Varying inputs of lime and fertilizer to adjust spatial differences in soil pH and available soil nutrients to optimal levels is another site-specific field operation. One of the most common methods of determining an application map is from soil sampling. In Cedar Falls, Iowa, Reichenberger (1998) reported that a manure spreader was implemented to vary rates of manure in fields based on intensive soil samples taken from 0.75-ac grids. These samples revealed spatial variance of nutrient levels, and tested manure was applied accordingly.

Pierce and Warnck (2000) examined the efficacy of variable-rate lime applications based on grid sampling for soil pH. Granulated lime was applied based on maps interpolated from the samples. However, the lime requirement interpolations were consistently underestimated. Corn yields in this experiment did not respond for production years 1995 and 1996, however, soybean yield did increase in 1997 due to liming. This study concluded that higher sampling intensity might be needed to accurately define variable lime application zones. However, to be economical for farmers a real-time sensor to determine soil pH may be required.

Lowenberg-DeBoer and Aship (1999) conducted a study involving discrete site-specific management of phosphorus (P) and potassium (K) to determine whether returns differed between grid, soil type, and whole field management (WFM). To derive an application map, WFM was based on average soil sample while grid management was based on samples within a 10-ft radius, and soil type management was based on a digitized soil map. Although site-specific P and K management did not increase any of the returns, the main effect on the physical quantities of P and K was redistribution of nutrients within the field.

Another example of varying rates of fertilizer is applications derived from previous yield data. Once differences have been identified within a field, the amount of fertilizer applied can be consistent with crop removal (Peterson and Wollenhaupt, 1998). This approach avoids a buildup of nutrients in areas that fail to produce.

Application of nitrogen (N) to winter wheat using a sensor-controlled variable rate applicator is another method of applying fertilizer site-specifically in real-time that has been demonstrated. Stone et al. (1996) established a correlation between a plant-nitrogen-spectral-index (PNSI), and total N uptake in wheat forage using an integrated sensor, consisting of photodiode detectors and interference filters, and a signal processing system. Based on these PSNI readings, N was applied to 3- x 3-m plots. Plots receiving variable rates were compared to a fixed rate plot. Results showed that the yields were not significantly different, but the variable rate plots resulted in savings of 32-57 Kg N ha⁻¹.

Seed Application

Site-specific seeding is another of these field operations that demonstrate a distinct on/off pattern where planting did or did not occur. A simple example of site-specific seeding is replanting selected areas in a field. The need for this may occur because of crop damage in certain areas of a field due to insects, weeds, diseases, natural disasters, or mechanical failures during planting. Once problem areas are determined, an operator can locate these areas in real-time and replant the crop.

Another form of variable rate seeding is an application based on field parameters. Seed varieties as well as seed populations can be varied based on soil type, slope, and moisture conditions (Batte, 2000). Veris technologies developed a system to measure soil properties down to a depth of 3 ft. (Veris, 2000). Although readings from the Veris system are not capable of controlling a

planter in real-time, application maps can be made from the readings to vary population rates based on cation exchange capacity (CEC) and topsoil depth.

Tillage

Varying tillage within a field is another site-specific operation. Fulton et al. (1996) conducted an experiment in Versailles, Kentucky, where a 7.06-ha field was subdivided into 30.5-m grids. These grids were sampled at the center for bulk density, cone index, and moisture content. Due to repetitive soil traffic, they found areas of higher soil compaction within the field. An application map was generated, and Fulton et al. (1996) concluded that discrete site-specific tillage could have resulted in a 50% reduction in fuel consumption compared to subsoiling the entire field.

Another form of site-specific tillage that is being tested is tillage based on remote sensing. Wells et al. (2000) assessed remote sensing for the implementation of precision tillage. A field of corn in Shelby County, Kentucky, was evaluated for yield variability, and it was noted that some areas of the field had substantially lower yields. Based on previous cropping history, along with yield suppression, soil compaction was evaluated using a cone penetrometer. Then, using a remote image after a rainfall, the researchers attempted to find areas with poor drainage. However, they found a low correlation between reflectance values and the cone index. In conclusion, they suggested that other strategies, such as passive microwave reflectance and synthetic aperture radar, should be investigated due to the substantial savings that would result in precision tillage based on remote sensing.

Insecticide Applications

A variable rate application of insecticide is another method of site-specific farming. One intensive method of determining field areas needing insecticide application is scouting. Maps can be developed by field scouts for many crop pests. Using these principles of integrated crop management to apply pesticide has the potential to reduce usage up to 80% (Robertson, 2000). Petrzalka et al. (1997) evaluated a program that encouraged farmers to adopt integrated crop management. In this study, crop consultant professionals scouted crops for insects. Farmers using discrete spot treatment, based on scouting of insect infestation levels, rather than broadcasting insecticide, reported savings were worth the additional time and effort.

Dupont et al. (2000) used scouting to verify and develop a method of remote sensing for insecticide applications. In this study 1023 ac of cotton planted in 10-, 30-, and 40-inch rows, in Bolivar County, Mississippi, was evaluated for a variable rate insecticide application. The researchers, knowing that insects prefer to feed on tender squares and healthy regions, could easily determine insect infested areas with remote images from an airborne digital camera. Intensive scouting proved the validity of these areas. Next, a prescription map was developed, and then the fields were discretely sprayed. Dupont et al. (2000) concluded in the 1999 growing season, reductions of insecticide were nearly 40%.

Plant Growth Regulators

Variably applying plant growth regulators is another method of site-specific farming. Tests conducted in Bertie County, North Carolina, compared grid and random sampling to determine spatial variability in cotton plant height (Thurman and Heiniger, 1998). A 14-acre field was sampled for 4 weeks during the bloom period. The study concluded that the grid sampling identified plant growth zones for the field. In addition, they concluded that the variability of the field was wide enough to justify a site-specific application.

Dupont et al. (2000) determined that remote sensing could be used to discretely apply growth regulators based on an application map. During an experiment to selectively apply insecticide, the farm owner found the areas in need of insecticide were also in need of the plant growth regulator PIX (Mepiquat Chloride). By using this method, the researchers only applied the regulator to the tall plants leaving the slower growing areas a chance to catch up over the growing season and produce an average yield. Therefore, it was determined they could use remote sensing to apply the plant growth regulator PIX to inhibit vegetative growth.

2. Data Acquisition Systems

Generally, there are two techniques used for conducting site-specific field operations. One technique is an application based on historical data that has been previously collected. Applying fertilizer to a field based on grid soil sampling is one example (Doerge, 1999) (Shearer, 1999). In these experiments,

an application map was generated by GIS and transmitted to a datalogger that controlled where the application took place. The other type of application uses decisions generated in real-time. A selective type sprayer such as Weedseeker (2001) is an example of a real-time discrete application. In this example, the treatment is based on information at the time of application, and no spatial information is stored.

When the operation is conducted using previously collected data, the application map serves as a prescription and a record of the application. However, when the operation is conducted in real-time, there is no prescription map. Often, it is important to document the operation. This provides a record of the operation, and in addition, the information can be used to evaluate the effectiveness of the operation.

A great deal of attention has been focused on the reduction of inputs through precision farming. Yule et al. (1999) developed a data acquisition system to monitor in field performance of a tractor. Transducers were mounted to measure engine, wheel, and ground speed in addition to fuel consumption, slope, and forces acting on the three point hitch. In combination with GPS, each parameter was associated with a geographical position and mapped. This information can be evaluated and equipment operators can become more efficient.

In another example, Tsunemori et al. (2000) conducted a study with four Patchen PhD 600 sensors mounted on the front of a utility tractor that was equipped with a Trimble Ag 132 GPS receiver, and an IOTech DaqBook / 100

data acquisition device. When the DaqBook received a sensor signal, it transmitted them to a laptop computer. The custom software then read the signal and simultaneously recorded geographic location for post-processing.

Beck and Kinter (1998) were issued a patent on Sep. 15, 1998, for an agricultural implement having multiple agents for mapping fields. This system contains a member that supports a plurality of sensors that traverse parallel paths as the attached vehicle moves across a field. A control unit is configured to automatically assign each sensor unit a unique address based upon the physical location of each sensor. Information indicative of the presence or absence of weeds can then be combined with information of the vehicle position to create a weed map. However, this system was not available at the time of study.

3. Selective Sprayer Systems

Two available selective-type sprayer systems, Detectspray and Weedseeker, have been tested in site-specific herbicide applications. These systems operate on the principle of reflectance values from the field of view (FOV) for a given sensor. These sensors contain filters that only allow red light (R), 645 nm, and near infrared light (NIR), 850 nm to pass through (Biller, 1998). The ratio NIR / R is then determined to distinguish the difference between soil and plant. This is possible because ratios for soil range between 1 and 1.5:1, while a plant ratio will range between 6 and 15:1 (Biller, 1998). However, many factors can affect the operation of this type of system: atmospheric conditions and time of day; plant species, size, and density; and stubble height and density.

Detectspray

Time of day and time of year was a concern of the study conducted by Blackshaw et al. (1998) on the Detectspray system. Experiments were conducted at various times of the day and year to determine the detection of weeds. The recommendation is that the ambient light reading be at least 0.4, and for optimum at least 0.65. These values have no specific units, and are relative to the monitor and system. It was found to achieve an ambient light reading of 0.4 the operator must wait 60 minutes after sunrise, and to achieve an ambient light reading of 0.65 the operator must wait 80 minutes after sunrise. Likewise, it was recommended to stop spraying the same amount of time before sunset. In addition, the time of year had no effect on the time after sunrise and before sunset. The time of day and time of year recommendations were based on cloud-free days. For maximum detection of weeds, the Detectspray ambient light readings should be at least 0.65 during operation of the sprayer system.

Weed species, size, and density affect on the Detectspray system was another factor studied on the Detectspray system (Blackshaw et al., 1998). Three species, wheat (grass), canola (broadleaf), and kochia (rosette), were tested in the 2-, 4-, 6-leaf, and 25-cm tall growth stage, at densities of 10, 30, and 75 plants / m². Wheat was found to be detected at the 6-leaf or larger stage regardless of density, however, the smaller plants were detected when densities were >70 plants / m². Canola was detected in the 2-leaf stage at densities >70 plants / m², 4-leaf stage at densities > 25 plants / m², and the 6-leaf stage at

densities > 12 plants / m^2 . Kochia was easily detected at >8 cm in diameter, however, it missed plants <8 cm in diameter.

Stubble height and density affect were also studied on the Detectspray system by Blackshaw et al. (1998). It was found that an increase in stubble height from 15 to 30 cm decreased detection on small plants by 11 to 34% (foxtail), and 22 to 60% (pigweed) depending on density of stubble. At a stubble height of 15 cm, densities from 75 to 300 stalks / m^2 resulted in a decreased detection by 34% (foxtail), and 32% (pigweed). Stubble height and density had no effect when a plant reached the 8-leaf growth stage, therefore, stubble height and density was only a concern when application was made to small plants.

Weedseeker

The Weedseeker system, manufactured by Patchen, emits a light source at a high frequency and measures the reflective value of this light to determine the presence or absence of weeds (Weedseeker, 2001). This design allows the unit to operate without regards to ambient sunlight, and also removes concern for time of day application. In addition, this unit can be operated in a hooded sprayer used to apply non-selective herbicide in row crops.

Hanks and Beck (1998) compared the Weedseeker system housed in a 0.7-m wide hood to a conventional hood. A separate supply tank was used for the conventional and the selective sprayer system. The amount of fluid used from each tank was recorded and calculated for difference. Overall reduction in volume sprayed for the Weedseeker was reported up to 82%. In addition, no difference in weed control was noted between the two systems.

CHAPTER III

METHODS AND PROCEDURES

1. Data Acquisition System

The Department of Agricultural and Biosystems Engineering (ABE) at The University of Tennessee developed a data acquisition system (DAS) to record and reference GPS coordinates with a real-time discrete on/off signal from a selective-type sprayer. This DAS was comprised of a Data Recording Unit (DRU), an interface box, and GPS (figure 1). These components worked together to record data that was necessary to generate an application map.

The interface box was designed to optically isolate the sprayer system from the DRU, and convert the analog sprayer signal to a digital signal that was input to the DRU. In addition to the nozzle status, GPS coordinates were input to the DRU. Each nozzle was scanned 138 times per second to determine the on time. The percent of time that the sprayer nozzle was activated between each GPS coordinate was calculated by the DRU and geo-referenced to the succeeding coordinate. After 60 GPS coordinates the UTC, GPS status, GPS coordinates, and nozzle data was saved to a file on a storage card (figure 2).

Data Recording Unit

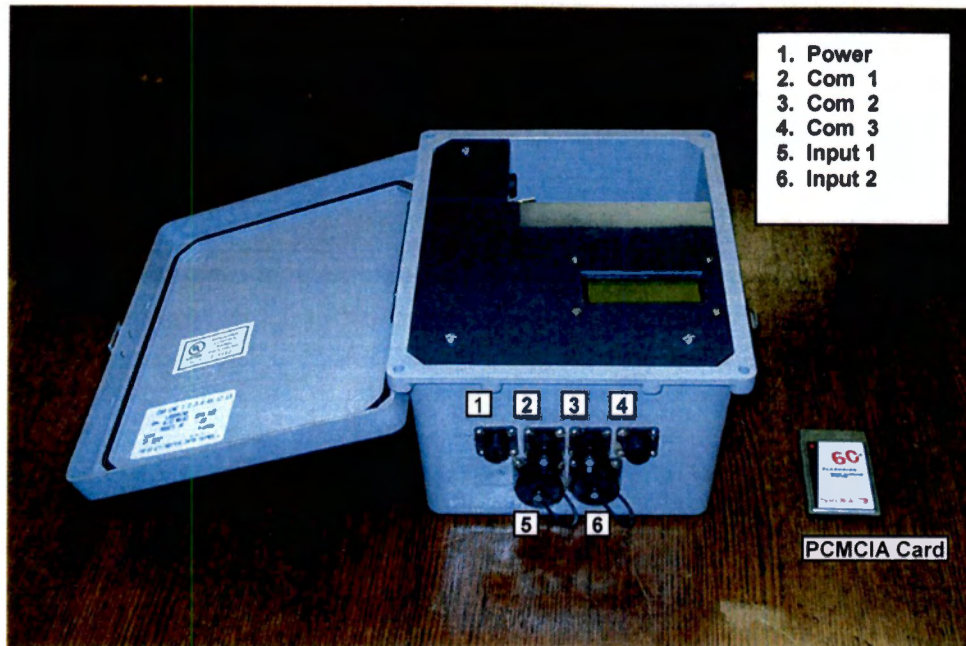
The DRU was used to process and store spatial application information about the selective-type sprayer. Housing for the unit was provided by a

9.75 in. x 11.5 in. x 6.5 in. industrial fiberglass weatherproof NEMA 4X enclosure. Inside a door on the housing was a control panel with a power switch to turn the system on, a red LED to indicate when the DRU was on, and a green LED that flashed each time a GPS signal was received.

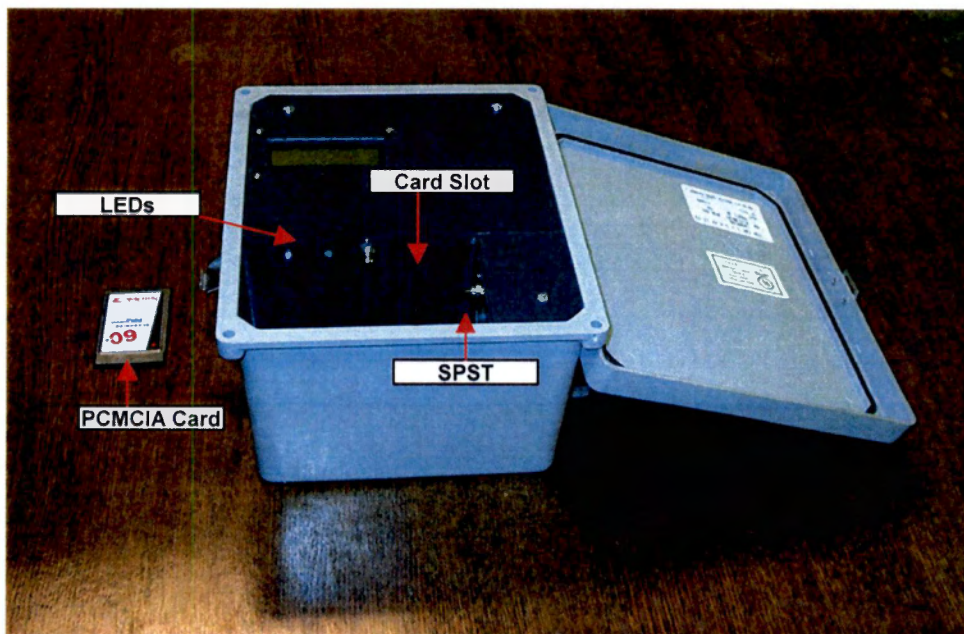
An Octagon Systems model 4010, 486-25 MHz CPU preformed the data processing of the DRU. This single board computer (SBC) processed signals from the interface box and referenced it with GPS data received from an external GPS receiver. The spatial data was recorded to a removable solid-state 60 MB PCMCIA "FLASH" card (SanDisk), which was located inside the enclosure.

After 60 GPS message sets from the GPS receiver, the green LED remained illuminated for 1 second signifying that data was written to final storage. The DRU software was designed to record information from 24 nozzles at 1 Hz. Based upon this setup, 1 MB of memory was required per 2-hour collection period.

Located outside the enclosure were six connectors as shown in figure 3: power, com 1, com 2, com 3, input 1, and input 2. The power connector supplied +12 Vdc to operate the system, while com 1, 2, and 3 connectors provided serial communication to the DRU. Com 1 interfaces with a separate computer for adding, removing, and upgrading software along with diagnostic checks on the system. Com 2 connected to a separate computer to view information processed by the SBC on a monitor, and com 3 connected with a GPS receiver to establish geo-referenced data for the system. Inputs 1 and 2 connected to the interface box to collect the nozzle status of the sprayer systems.



a. bottom angle



b. top angle

Figure 3. DRU used to process and store data for the DAS. Bottom angle (a) shows the connections to the DRU, while the top angle (b) shows control points for the DRU.

Interface Box

An interface box was necessary to convert the analog signal of each nozzle to a digital signal, and provide an optically isolated signal back to the DRU. On this box were five connectors as shown in figure 4: Nozzles 1-15 input, Nozzles 16-24 input, Data Cable, Nozzle 1-15 output, and Nozzle 16-24 output. This interface was also designed and built by ABE inside a 6.5 in. x 7.0 in. x 4.5 in. weatherproof enclosure. The interface box consisted of opto-isolators, which were connected to the +12-Vdc signal from the solenoid of each nozzle. A voltage drop from each solenoid activated an opto-isolator, which converted the analog signal to a digital signal. This signal was sent to the DRU to be recorded and referenced with a GPS coordinate.

GPS

A Trimble AgGPS 132 receiver was used with real-time differential correction supplied by Omni Star. The differential correction provided the system with sub-meter spatial accuracy. This particular unit had NMEA 0183 output, and Everest Multipath Reduction installed. Using port A, configurations were set for the GGA NEMA string to be output at 1 or 2 Hz using a 4800-baud rate. These settings were necessary to be recorded by the DRU.

Data Conversion

A QBASIC program, CONV6.exe, was developed to convert the raw data file from the DAS. This program, listed in appendix, required information from the user about the sprayer setup (figure 5). These parameters were used to project where the nozzles were located in reference to the GPS antenna. The program

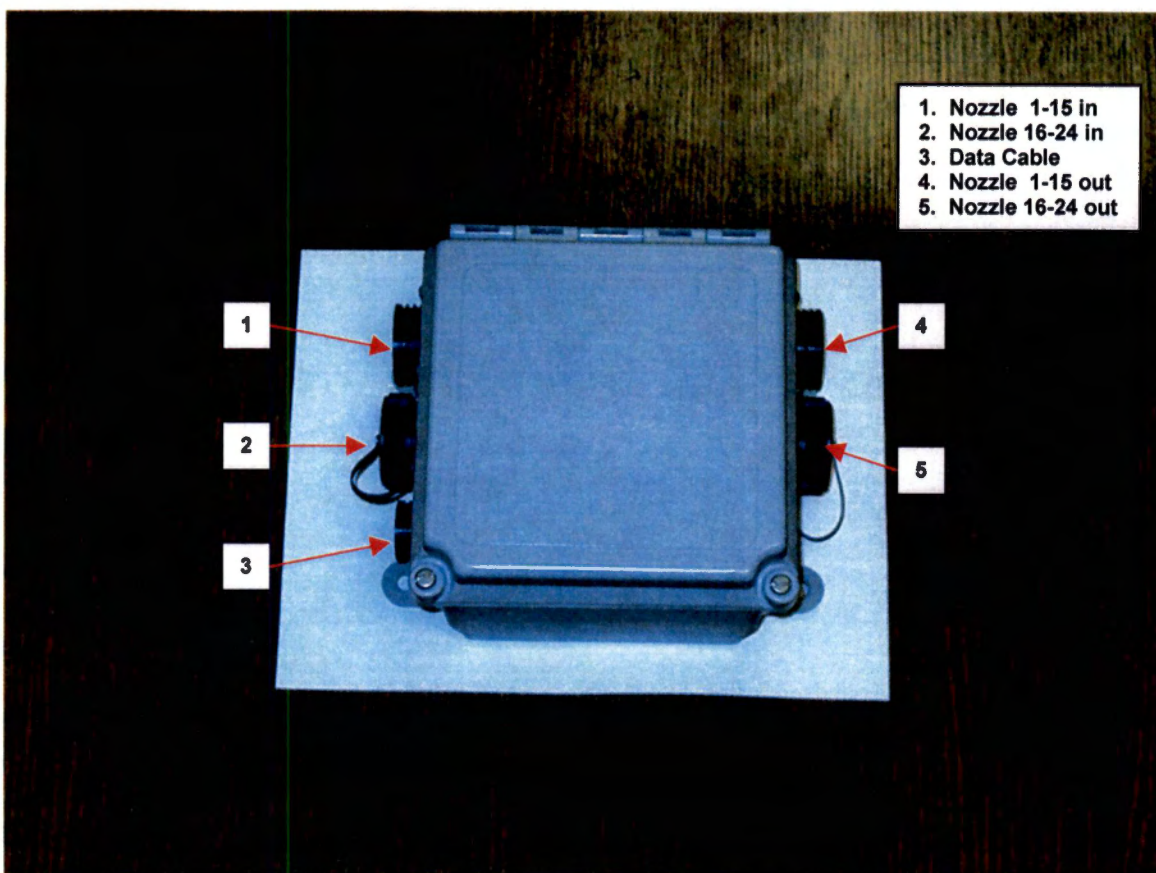
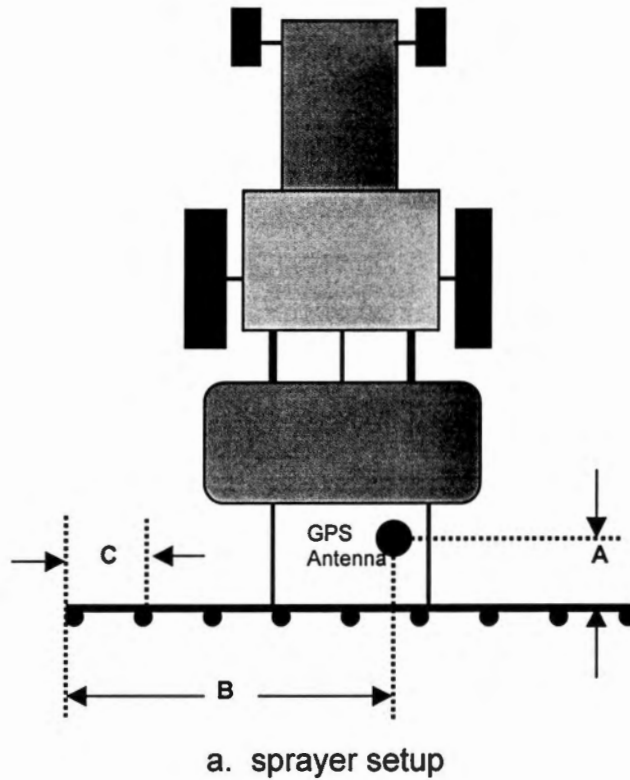


Figure 4. Interface box used to sense valve voltages, and convert to an optically isolated signal for the DRU for up to 24 nozzles.



C:\sssd\CONV6.EXE

Is the left-most nozzle:
 1. Left of the antenna
 2. In line with the antenna
 3. Right of the antenna
 Enter your choice <1-3> 1

Is the boom:
 1. In front of the antenna
 2. In line with the antenna
 3. Behind the antenna
 Enter your choice <1-3> 3

Enter the distance between the antenna and the boom in inches. 30 ← A

Enter the distance between the antenna center-line and the left-most nozzle in inches. 50 ← B

Enter the number of nozzles. 5

Enter the distance between nozzles in inches. 20 ← C

b. parameters required by convert program

Figure 5. Example of information required by the convert program to spatially project sprayer nozzles. Sprayer setup (a) is required by the convert program (b).

looks forward and backwards spatially to determine the velocity and vector of the spraying system, then assigns a projected coordinate for each nozzle. Once these steps and calculations were completed, three files were output (figure 6).

The first file, *filespec.inf*, is an information file that contains records about the raw data file. Included in this file are the raw file name, date recorded, time recorded, length of raw file, the second UTC for the GPS in the file, coordinates of the first and last point, and the number of GPS points with no position fix. The second file, *filespec.txt*, is a text file that contains the projected latitude and longitude for each nozzle, and percent on time for each nozzle. This file is used for analysis and mapping. The third file, *filespec.smp*, contains the average percent on time across the boom for each coordinate, and has three columns: latitude, longitude, and percent on for the average across the boom. This file can be used when less application detail is desired.

2. Spraying Systems

Selective Sprayer Systems

Two selective-type sprayer systems, Detectspray and Weedseeker, were used as the discrete on/off signal for the DAS. These systems were mounted on separate parallel booms to operate in a broadcast application. The equipped booms were attached to the mounting bracket at the rear of the sprayer. Each system required specific equipment that was located to achieve proper operation.

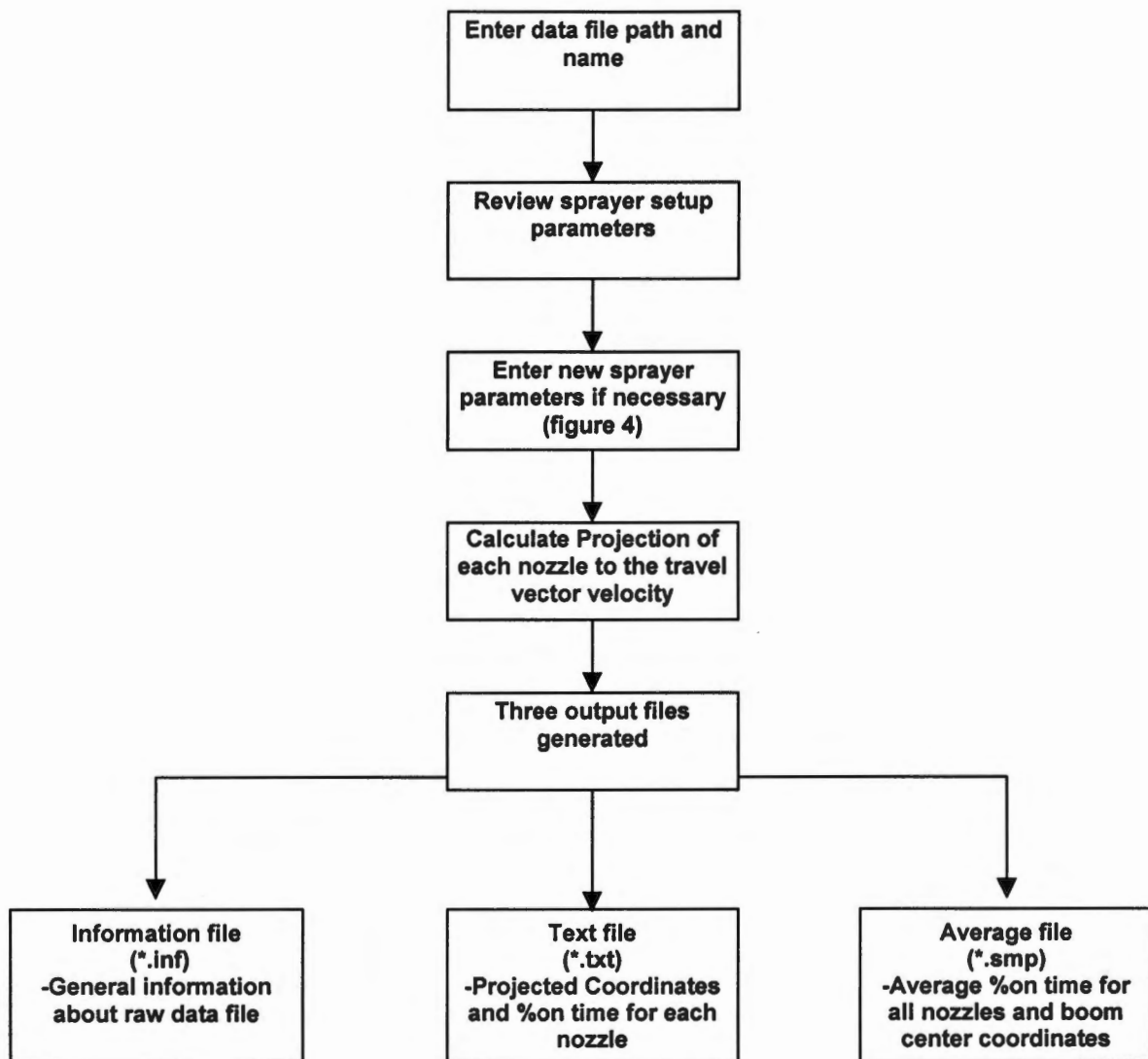


Figure 6. Flow chart for the program that converts data logged by the DAS into files that can be used to generate an application map.

A. Detectspray

For this research, enough equipment was obtained to equip a 100 in. wide boom. Based on 20 in. spacing, there were five solenoid controlled nozzles manufactured by Goyen Controls, five S-50 Spray sensors manufactured by Detectspray, and five sensor brackets spaced evenly across the boom (figure 7). There were also one master monitor manufactured by Detectspray, and various wiring harnesses from Fargo Assembly to connect the system.

B. Weedseeker

To obtain approximately the same swath width as Detectspray, a 108 in. wide boom was equipped with the Weedseeker system (figure 8) manufactured by Patchen. To control the system a Patchen model CCP controller was used. Based on 12-in. spacing, two model 650 Weedseeker units, and seven PhD 600 Weedseeker units spanned the boom. Each of the nine units contained a VDC05 valve driver cartridge (figure 9) designed to control an external solenoid, which replaced the solenoid controlled spray nozzle. The VDC05 connected directly to the interface box that sent the signal to the CPU. In addition, various cables, manufactured by Patchen, were necessary to complete the system.

Sprayer and Equipment Mounting

A 55-gallon 3-point hitch boom sprayer equipped with a Hypro series 6500 6-roller pump (figure 10) was used to attach equipment and supply fluid to the sprayer. A mounting bracket was designed and attached to the original sprayer frame to facilitate mounting of the DAS and sprayer booms (figure 11). Nozzles were positioned for broadcast applications.

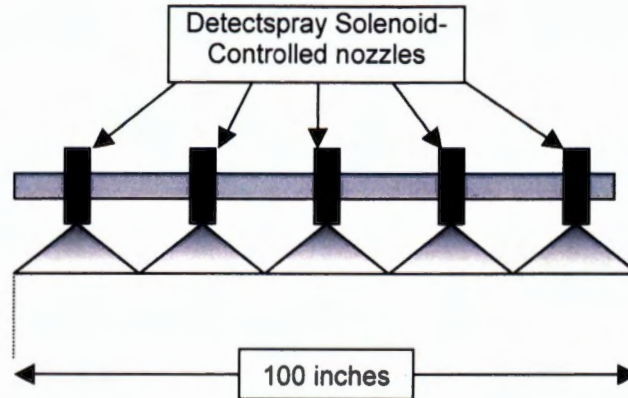


Figure 7. Schematic illustrating setup for the Detectspray system which included five units spaced evenly across the 100 in. boom.

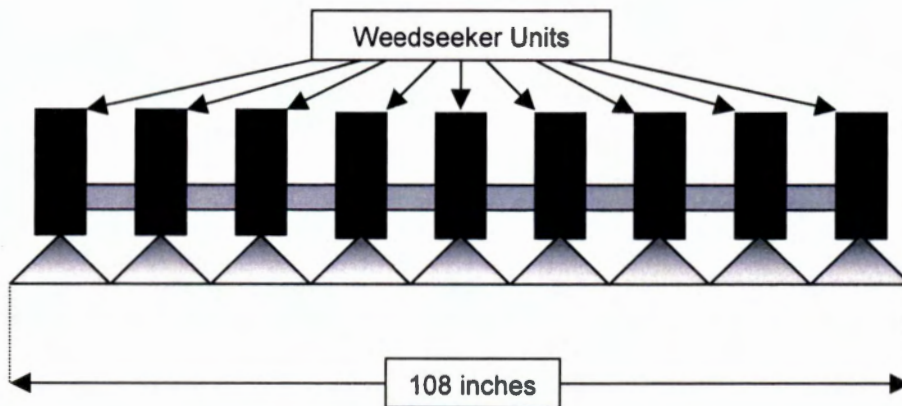


Figure 8. Schematic illustrating setup for the Weedseeker system which included nine units spaced evenly across the 108 in. boom.

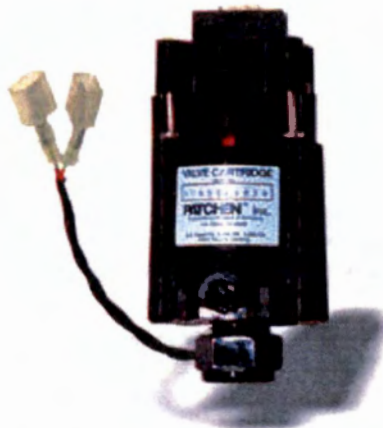


Figure 9. The valve driver cartridge (VDC05) replaced the solenoid-controlled nozzle in the Weedseeker units to send a signal to the interface box.



Figure 10. Sprayer and roller pump used to mount DAS and selective-type sprayer for field data acquisition.

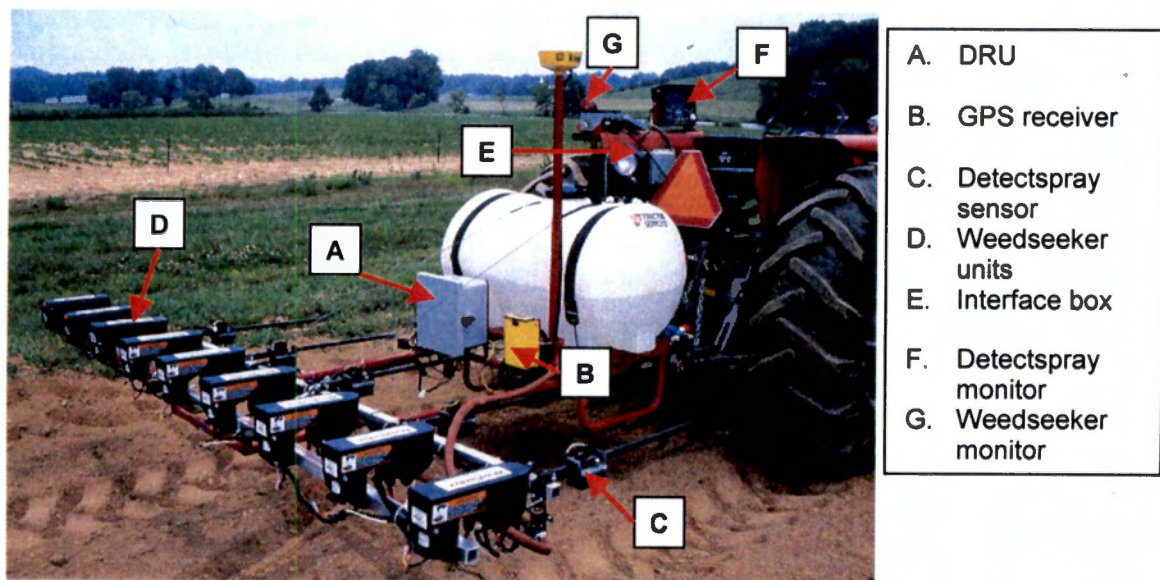


Figure 11. DAS and selective-type sprayers attached to the rear of the original sprayer using a mounting bracket.

This bracket provided the ability to mount the two selective-type sprayer systems, and the DAS for field operation. Due to excessive weight and length of the frame, a steel cable was used to support the bracket mounting system. This cable attached to the rear of the mounting bracket, and ran from the rear left and right side to the top front center of the sprayer frame.

The main portion of the attachment was fabricated using 1 in. square tubing. Total length of the attachment from front to rear was 48 in. The first section was 30 in. long with two 26 in. cross-members. The second section was welded to the rear cross-member of the first section, and was 18 in. long by 20 in. wide

To mount the CPU and the GPS receiver, 1 in. angle iron was welded to the front of the attachment. The GPS antenna was threaded onto a pipe, which was welded beside the GPS receiver. This pipe positioned the antenna to receive optimal signals from the GPS satellite vehicles.

The two booms were mounted to the rear of the attachment. The Detectspray system was mounted on the boom closest to the spray tank. This boom's operational position was 30 in. from the front of the attachment and 20 in. above the soil. The Weedseeker Boom was 18 in. behind the Detectspray boom and operated 23 in. above the soil surface.

Over the course of the field experiments the sprayer control monitors were mounted on a Massey Ferguson 265, and a New Holland TN70 agricultural tractor. On the MF265, the monitors were secured to the tractor fender, and on the TN70 the monitors were attached to the rollover protection system.

3. Field Testing

Field tests were conducted at two locations to evaluate two selective-type sprayer units using the DAS. Vegetation patterns for each location were established for system performance of each sprayer system. The first field test had a known vegetation pattern, and was performed at The University of Tennessee Milan Experiment Station. This test was conducted to generate an application map of a distinct vegetative pattern, and compare that map to a geo-referenced vegetation map. However, the second field test had random vegetative cover, and was performed at The University of Tennessee Knoxville Experiment Station. This test was conducted to generate an application map from the system in actual field conditions, and compare that map to a vegetation map generated from remote images.

Known Vegetation Pattern

A known vegetation pattern was established using soybeans at Milan Experiment Station to test the DAS (figure 12). By using this known vegetation pattern, a distinct on/off signal was sent to the DAS to be referenced with GPS. The vegetation pattern was geo-referenced for comparison between the known vegetation pattern and the DAS's application map. Tests were performed at 2.5 and 5.8 mph to determine effects of velocity.

To create this known vegetation pattern, soybeans were planted with a 15 ft. wide John Deere 450 seed drill. Rows were planted in one direction, and then moved over approximately 3.5 in. to plant between the 7 in. rows to achieve a dense coverage. Next, the drill skipped 30 ft. and planted another pass of beans

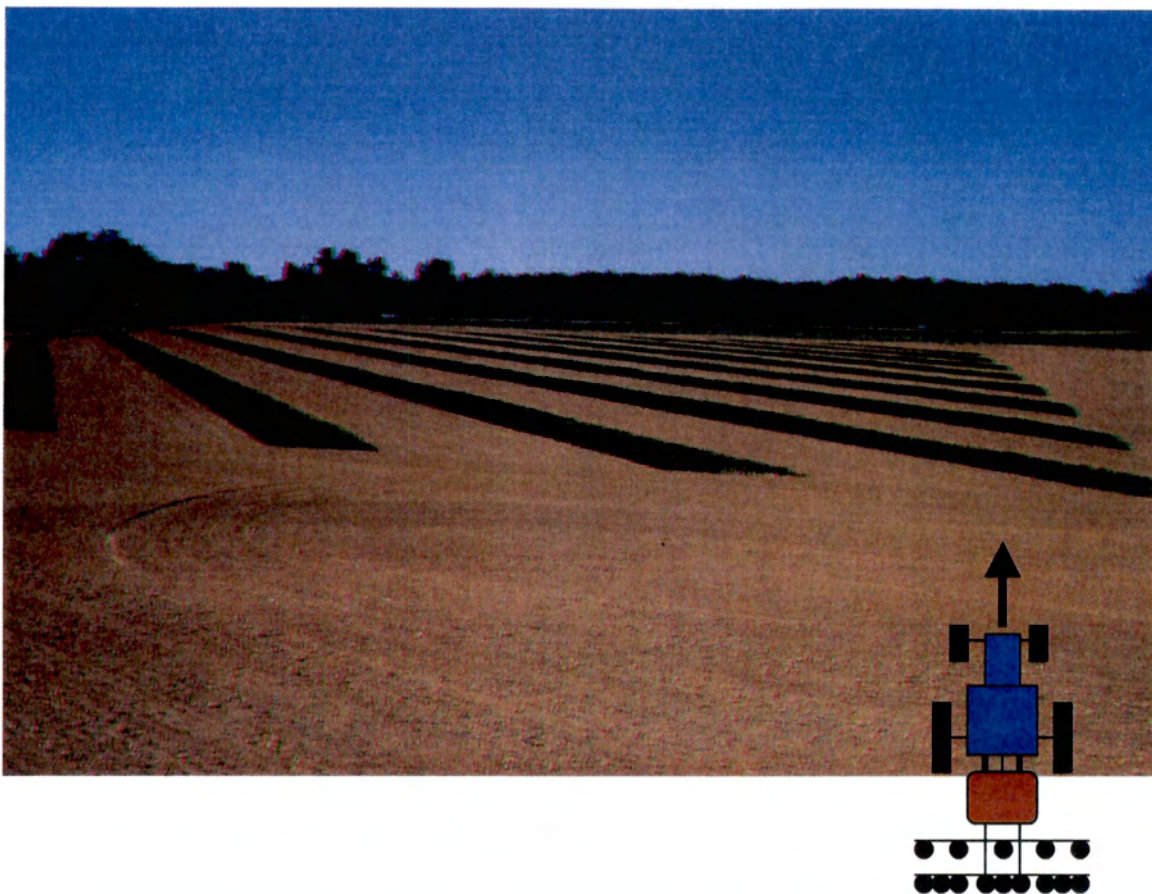


Figure 12. The known vegetation/soil pattern was setup using 15-ft. wide soybean rows with 30 ft. between these rows to generate a distinct on/off pattern. Spray travel direction was oriented at a 45-degree angle to the soybean rows.

as described above. Each of the rows was planted at a 45-degree angle in respect to the corners of the square field. The pattern was repeated over the five-acre field.

This pattern was established to allow a minimum of two points to be referenced in the vegetation area, and four points over the soil area for the 5.8 mph test. The rows were planted at a 45-degree angle to the direction of travel to activate each nozzle at separate times. This process tested the DAS accuracy of recording separate information about each nozzle.

Prior to spraying, a multipurpose secondary tillage seedbed preparation tool was used to cultivate 30 ft. between the unplanted rows. This assured a vegetation free area to create the off signal for the DAS. Both selective-type sprayer units were calibrated to the vegetation free soil before spraying.

The field was sprayed with rows at a 45-degree angle to the direction of travel at two ground speeds (2.5 mph and 5.8 mph). For each speed, a separate file was created for separate analysis. The complete spray system, DAS, and GPS were used to spray the field using water only. The New Holland TN 70 agricultural tractor was used to operate the sprayer for this experiment. This tractor was equipped with row markers made from 1 in. x 1 in. x 1/8 in. angle iron with a 3/16 in. log chain hanging from the end. These chains were designed to mark where the previous swath occurred and correctly position the tractor during each pass.

To geo-reference these soybean rows, the Trimbal AgGPS 132 was used. A range pole with the GPS antenna was held at the corner of each row, and a

laptop, which was connected to the GPS receiver, recorded several seconds worth of data. To increase accuracy, the points for each corner were averaged to obtain a single point. Points for the field were saved in a text file and imported into ArcView GIS 3.2 for analysis. Then the points were used as reference to create a polygon shape file that represented the soybean rows.

Random Vegetation Pattern

This experiment was conducted to generate random signals from the selective sprayer systems to the DAS. This was accomplished by allowing weeds to grow in a 0.5-acre plot. However, due to high weed pressure some areas of weeds were mechanically destroyed. A weed map was generated from remotely sensed images to determine where the sprayer should have been activated. In addition, 1 Hz and 2 Hz of the GPS output signal were used to compare performance of the DAS at the two frequencies.

Plots were tilled at random prior to spraying with a three-point hitch P.T.O. driven rotary tiller. This tiller was operated at a random weaving pattern (figure 13) throughout the plot until there was approximately fifty percent weed coverage remaining. A random pattern of tillage, plus the random weed densities, provided the optimal vegetative cover for the experiment.

The area required to conduct the experiment was 50 ft. x 175 ft. (figure 14). This was wide enough for the sprayer to make six passes; however, the two center passes were omitted leaving room for a bucket truck used to collect remote images of the plot. Therefore, there was enough area for four passes of the sprayer. These 16.67 ft. x 175 ft. isles were divided into seven blocks each

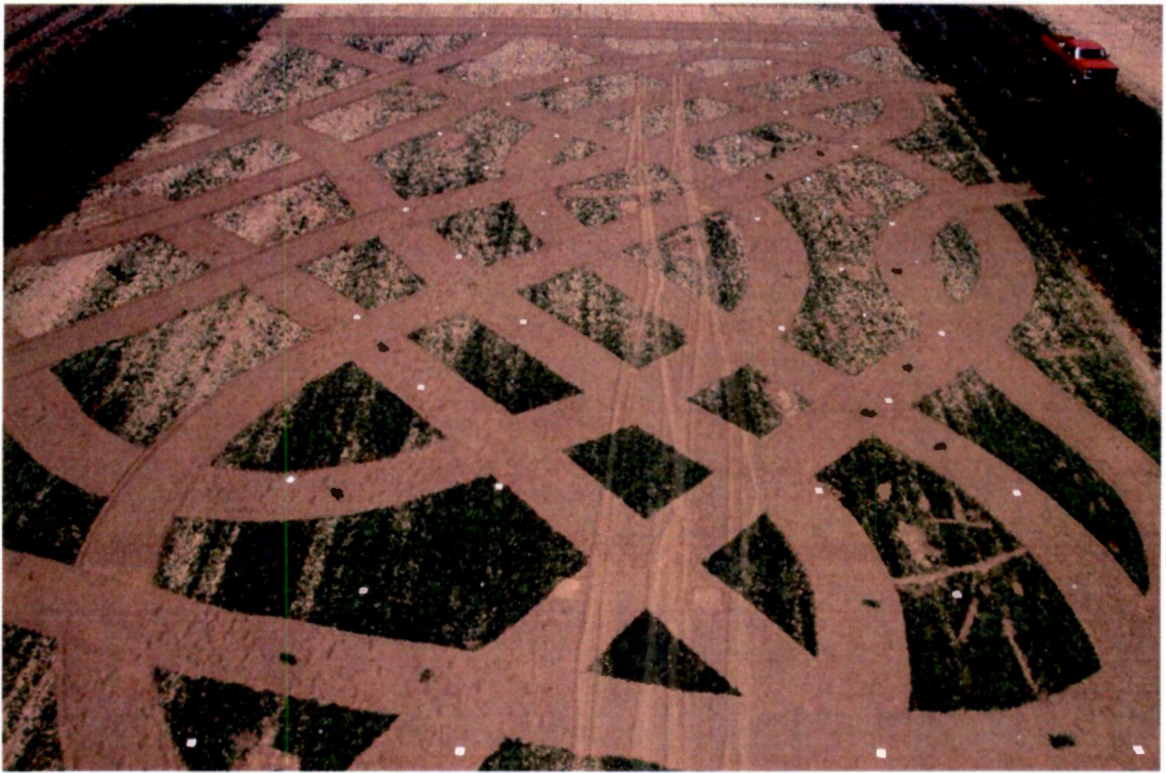


Figure 13. Random pattern test setup using a combination of random vegetation and tillage to generate the random on/off pattern.

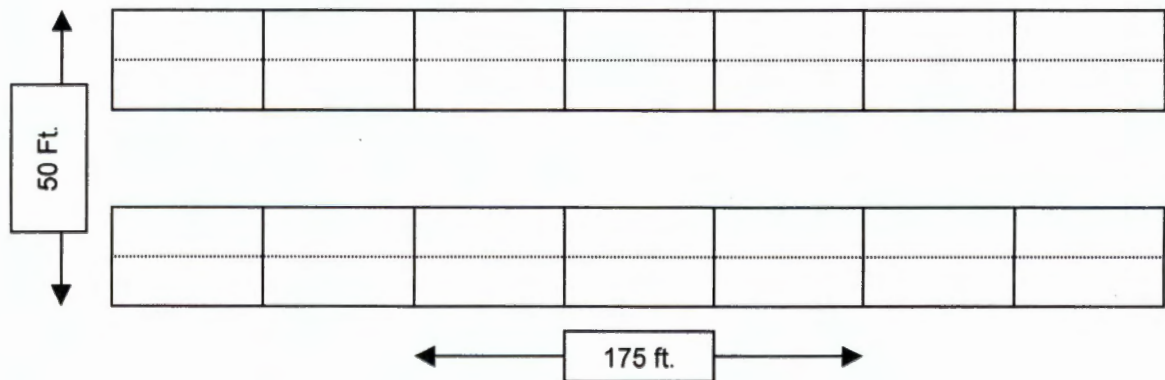


Figure 14. Field layout for the random pattern test consisted of a 50 ft. x 175 ft. plot laid out into 14 blocks.

for a total of 14 blocks. The blocks were designed for two sprayer swaths, and long enough for eight 1 Hz data points traveling at 2 feet per second (fps). In addition, each block represented an area used for a remote sensing image.

A 6-in. x 6-in. x 1/4 -in. plywood square was placed at the corners of each individual block (figure 15). Also, a square with the block number was placed in the center of the block. White marker flags were placed in line of the squares to serve as row markers to guide the sprayer. After equipping each block with the squares and flags, the area was ready to geo-reference and take the remote images.

The AgGPS 132 and a Hewlet Packard 200lx palmtop were used to geo-reference these squares. A range pole with the GPS antenna was centered in each square, and the palmtop, which was connected to the GPS receiver, recorded several seconds worth of data. For increased accuracy, the points for each square were averaged to obtain a single point. Points for the plot were then saved in a text file and imported into ArcView GIS 3.2, and used as a reference for the squares in the remote images.

A bucket truck was used to take unobstructed remote images of the blocks (figure 16). These images were taken at a height of approximately 50 ft. high. The bucket was positioned over the center of each block, and a zoom lens was adjusted to the size of each block. A photo, using a polarizing and a green filter, was taken of each block on slide film. These processed slides were then digitized to JPEG format, and imported into ArcView.



Figure 15. Block layout for the random pattern test consisted of four corner blocks and one numbered center block for geo-referencing.

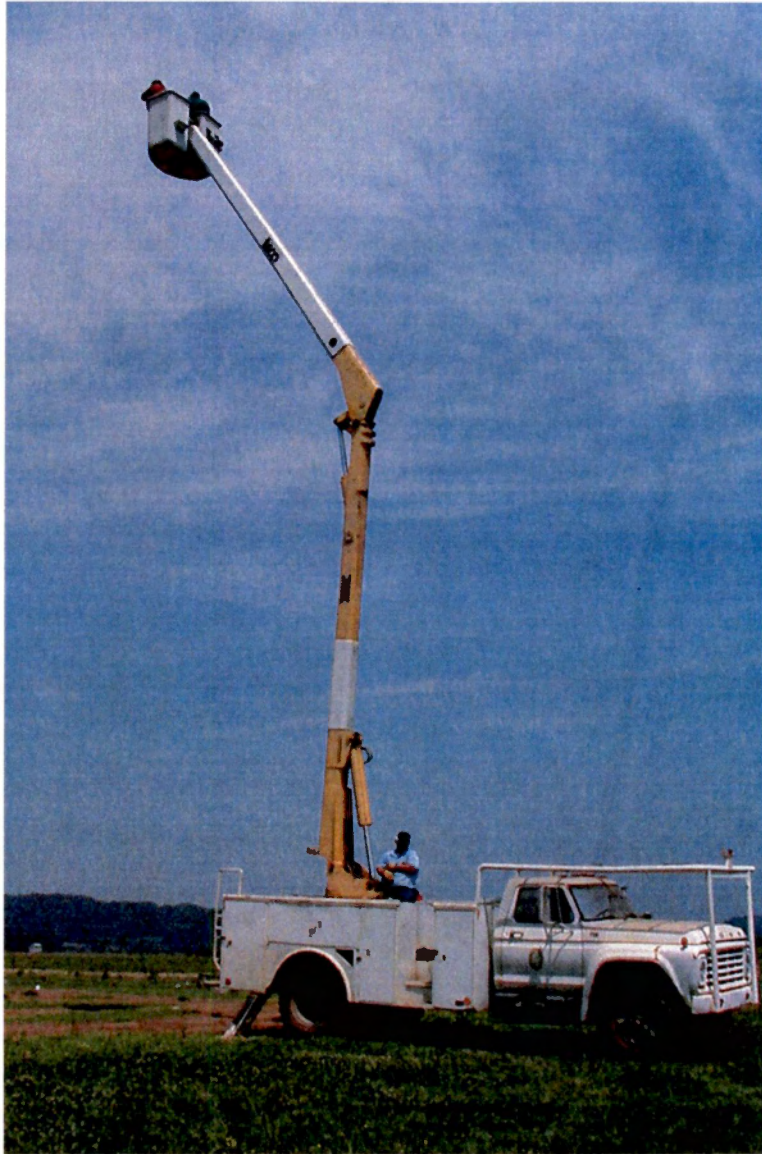


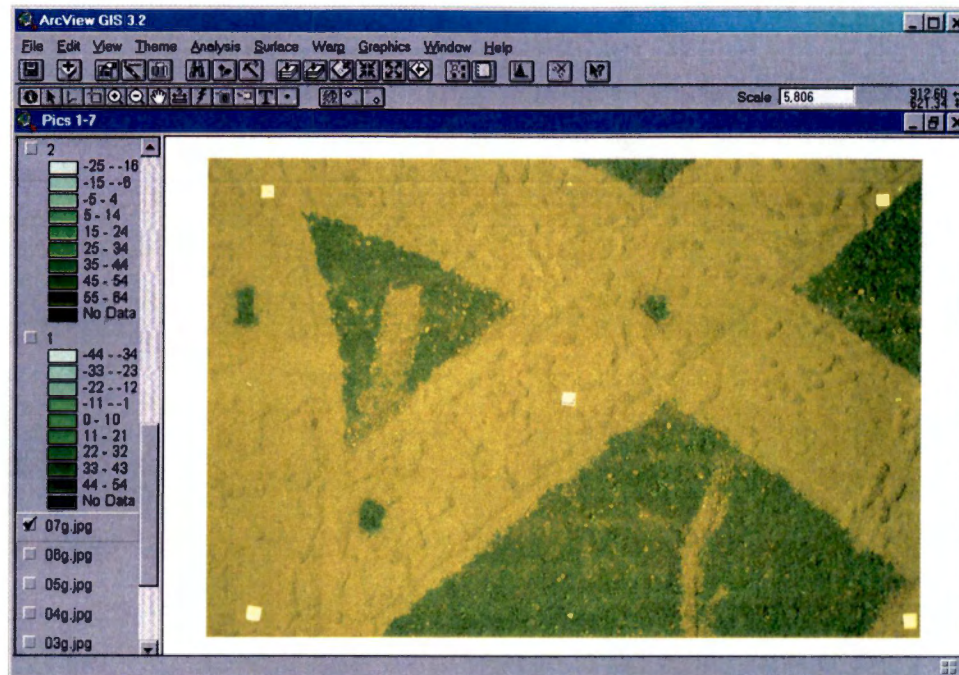
Figure 16. Bucket truck used to collect remote images of the blocks from the random pattern experiment without obstructing the view.

To open JPEG format in ArcView, a supporting extension was loaded. In addition, the spatial analyst and warp extension were loaded, as they were needed for later processes. Once ArcView was loaded with the extensions, a new view was created with the remote images.

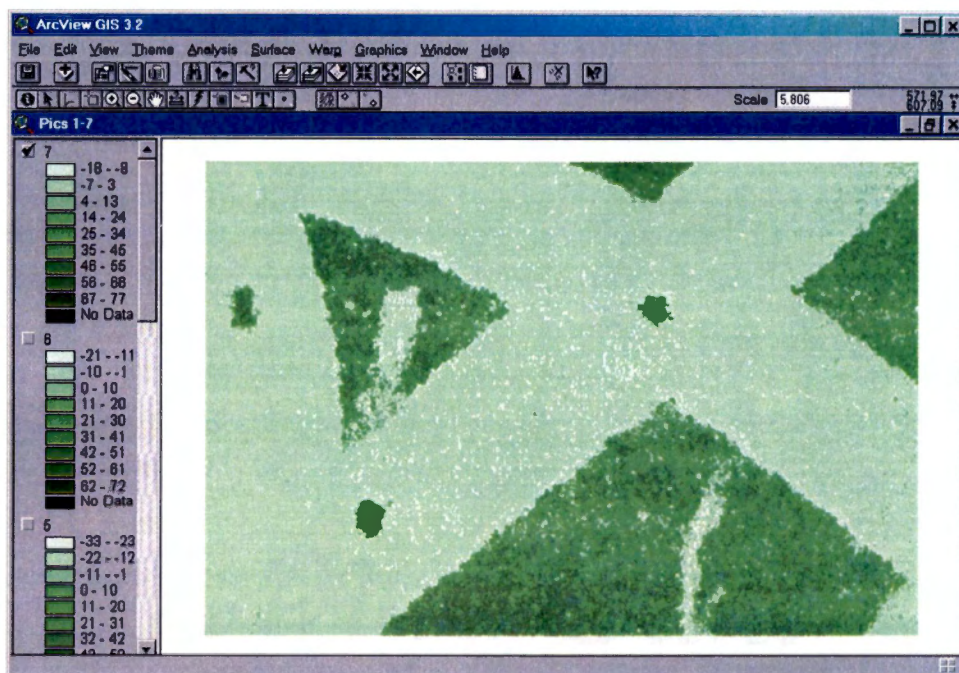
Spatial analyst was used to convert the image to a 0.5 in. x 0.5 in. grid. The image had three bands: red, green, and blue. The green band, however, included noise along with the vegetation. Further inquiry found that the red band highly contrasted this noise. As a result, the red band was subtracted from the green band using the GIS map calculator. The result is a weed map based on a graduated color as shown in figure 17. This calculation had negative value classifications that were not useful. These negative classifications were deleted from the theme, which then resulted in a weed map based upon a graduated value.

The resulting grid file for each image was geo-referenced by warping the grid with five control points. These control points were taken from the squares located in each image file. Each grid file was warped to the 1983 Tennessee State Planes projection.

Being only interested in where the weeds were, a map query was used on each of the warped images. This map query stated that all cells with a value over the lowest positive value in the map calculation be assigned a 1, and all values lower than that were assigned a 0. The value 1 cells represent weeds, and accordingly the value 0 represents no weeds. Thus, a vegetation map was generated.



a. image of block 7



b. vegetation grid

Figure 17. The image of Block 7 (a) was converted into a vegetation grid (b) based on weed density. This map was used for analysis of the application map generated from the DAS.

4. Volumetric Evaluation

A volumetric test was conducted using two Detectspray nozzles to verify what the DAS recorded was what actually occurred. Water was collected from each nozzle for a known period of time over which the nozzles were cycled on/off and compared to data recorded about their percent on time as recorded by the DAS. This test required two laptop computers, a single board computer, the DAS, an oscilloscope, the Detectspray system, a circuit board to control the LEDs, and artificial activation devices to activate nozzle sensors (figure 18).

The activation devices used in this test consisted of a single red LED located in a 4-in. x 4-in. x 2-in. PVC box that was positioned below each S-50 spray sensor. These LEDs emitted a red light that the sensors interpreted as soil because plants absorb red light. Therefore, sensors were calibrated to activate when the LEDs were turned off. These LEDs were switched on and off at a frequency of 1 Hz for various duty cycles. The on time for the LEDs was varied between 2 and 1000 milliseconds. Therefore, theoretically over time the nozzles should only be closed for the amount of time the LED was activated.

Nozzle flow was calibrated by collecting fluid for a known time. Then, a continuous flow rate was determined for each nozzle for a given pressure. When the system was switched on and off, a flow rate was also determined for that particular setting. This experimental flow rate was then divided by the continuous flow rate and multiplied by 100 to determine the percent of continuous flow. This percent flow was plotted and compared to the DAS record of each event.

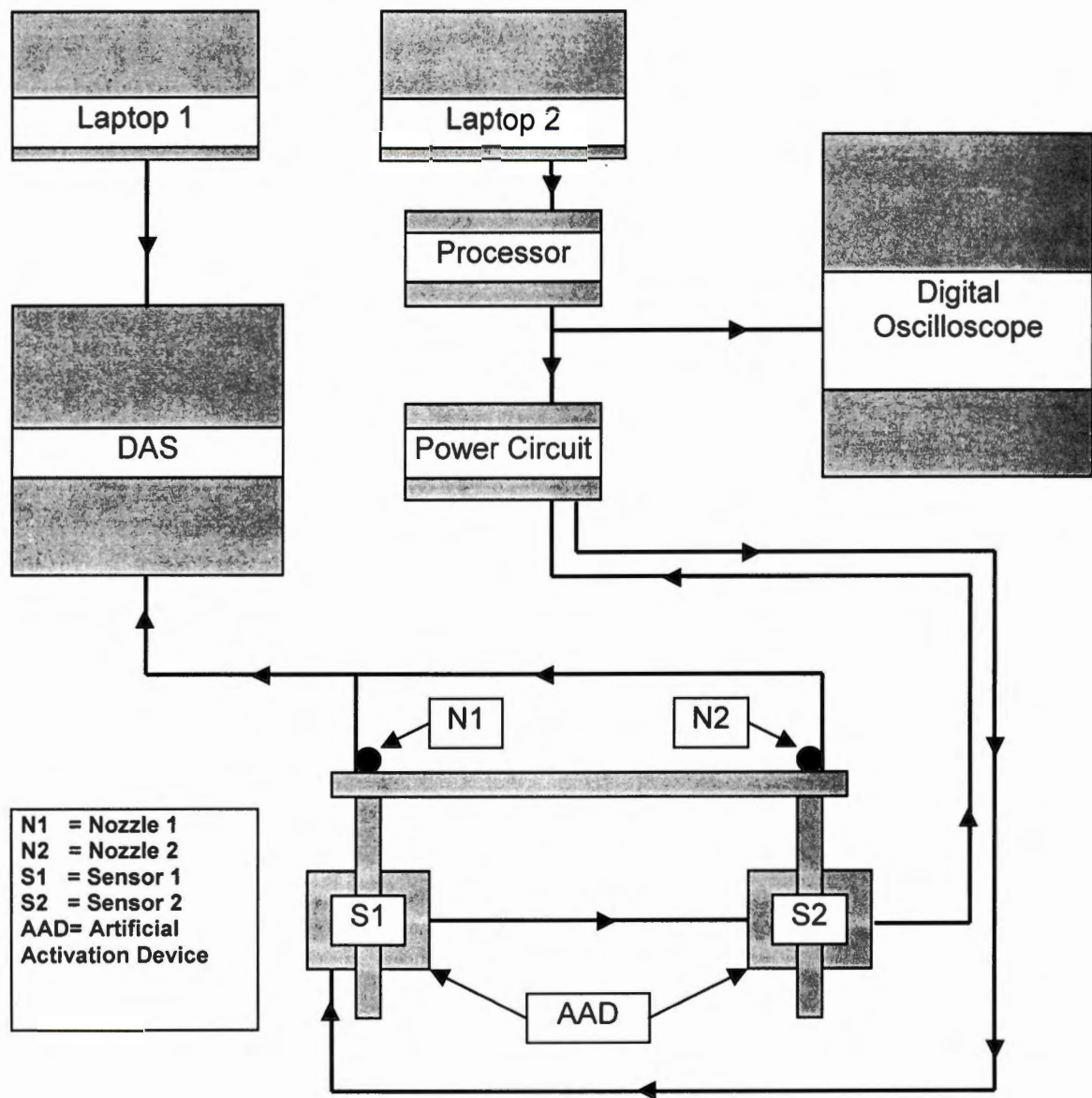


Figure 18. Schematic illustrating setup for the volumetric evaluation to artificially activate and record nozzle activity.

One laptop computer, Compaq Armada 1573 DM, was used to relay the frequency and duty cycle from a PBASIC program (figure 19) to a Parallax Basic Stamp II. This microcontroller was used to control the power circuit (figure 20) that turned the LEDs on and off at a known frequency and duty cycle. This circuit controls the current through the LEDs with a transistor. To verify the frequency and duty cycle of the LEDs, a Tektronix 2233, 100 MHz Digital Storage Oscilloscope was used.

The second laptop computer, Zenith Data Systems Z-star EX, was connected to the DAS through a null serial port connection. Since the DAS required GPS input for DAS timing, the second laptop emulated a GPS signal. The DAS was also connected to the nozzles to record nozzle activation.

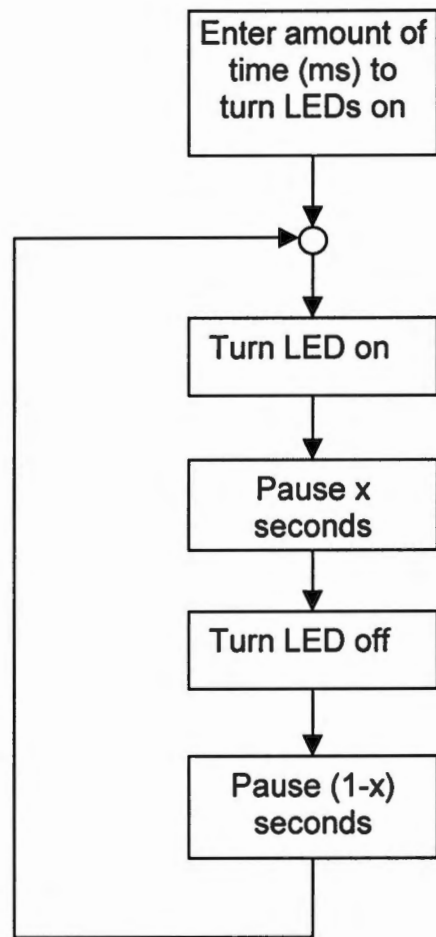


Figure 19. Flow chart representing the PBASIC Program used to send frequency and duty cycle to a SBC during volumetric testing.

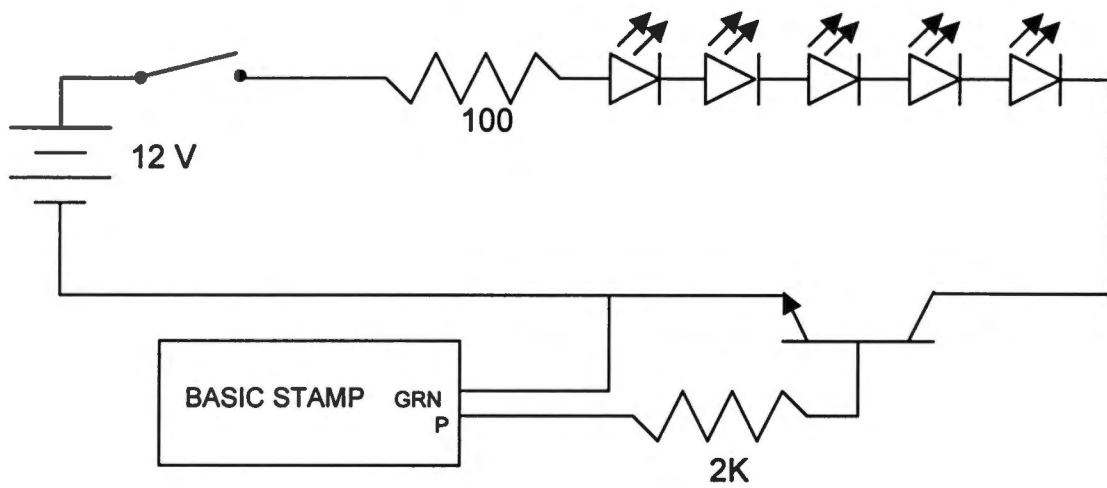


Figure 20. Circuit used to switch LEDs on and off during the volumetric test.

CHAPTER IV

RESULTS AND DISCUSSION

1. Field Testing

Known Vegetation Pattern

A field was setup to evaluate the DAS using a known soil/vegetative pattern to generate a discrete on/off signal from the selective-type sprayers. The DAS then recorded this on/off signal from the sprayer along with the geographic location of the activity. Both sprayer systems Detectspray and Weedseeker were calibrated and used in this experiment at two different spraying speeds. An application map was generated for each sprayer and speed. These maps were analyzed for hits, misses, and false triggers and then compared to the geo-referenced vegetation pattern.

A. Setup and Operational Factors

The sprayer units were calibrated for speed, individual sensor sensitivity, and complete sprayer system sensitivity. To determine speed of the system, the tractor was driven on a 200 ft. course in different gears at 1500 RPM. The amount of time required to drive this course along with distance driven was converted into mph. The speeds then selected were approximately 2.5 mph (slow) and 5.8 mph (fast).

For the Detectspray system the sensor was positioned in front of the solenoid nozzle 2 in. for every 1 mph. Therefore, the sensor was positioned 5 in.

ahead of the nozzle for the slow speed, and 11.6 in. for the fast speed. The Weedseeker system had an adjustment of high (7-10 mph), medium (4-6 mph), and low (1-3 mph) speed on the control monitor. For the slow test the adjustment was set on low, while during the fast test the adjustment was set on medium.

Next, sensor sensitivity was adjusted for the systems to calibrate the sensor to what was considered a vegetation free area. This was accomplished by placing the systems over an area of bare soil. The Weedseeker system was calibrated by activating a switch at the control monitor. However, the Detectspray system was calibrated by rotating a potentiometer inside each of the five sensors until the solenoid was activated, and then desensitized one rotation. This process repeated for each sensor, and then re-evaluated until all sensors were within a setting of 0.05 on the Master Monitor. For these tests the point where all Detectspray sensors came on was between 0.73 and 0.78.

Due to the distinguished vegetation area the sensitivity for each system was adjusted to a medium setting. The Weedseeker system was set at 5 with the options being a value between 1 and 10, 1 being the most sensitive and 10 being the least. The Detectspray system was set at 1.00, which was approximately 0.25 above the solenoids being activated on bare soil. This value was changed during the slow experiment to 1.10 because nozzle 4 was false activating between the rows. This setting also remained at 1.10 for the fast test.

Previous research discovered time of day was a factor in the operation of the Detectspray system (Blackshaw et al. 1998). However, these two

experiments were conducted within recommended times with minimal cloud cover to avoid this concern. In addition, a GPS site plan was generated, and times selected for each experiment was considered optimal for sunlight and GPS satellite vehicle position.

The slow experiment was conducted on September 19, 2000, between 3:30 P.M. and 6:13 P.M. Sunlight was optimal on this day according to a light meter that recorded values of 64,100 lux at 3:30 P.M. and 34,200 lux at 6:13 P.M. The fast experiment was conducted the next day between 11:30 A.M. and 1:15 P.M. Sunlight intensity for this test was also optimal with a reading of 54,000 lux at 11:30 A.M. and 63,700 lux at 1:15 P.M.

B. Application Maps

A data file was recorded for the slow and fast experiment for each unit. These files were then transferred to a desktop computer where the CONV6 program converted the raw data file. This projected data was opened in ArcView and application maps were generated for each spray system and speed. These maps display the geo-referenced vegetation pattern, an outline of the field, and the percent on time for each nozzle.

The vegetation pattern was based on GPS points taken from the corners of the soybean rows and used to create a polygon to represent these soybeans. This process creates less error than walking the perimeter of the polygon, because each corner point was averaged over a period. A new polygon theme was then created in ArcView that was used in the application maps to display the geographical location of the on signal. In addition, the bare soil background was

another polygon created to illustrate the perimeter of the field in interest, and to show the geographical location of the off signal.

Graduated values for the on-time were the percent of a second that the nozzle was activated. These values represented how the spray system reacted over the record period of 1 Hz. A value of 5% was chosen as the lowest point to display on the map. This removed the small values associated with opening and closing of the valves. Therefore, if the system was activated for less than 50 ms, then that specific geographic location was discarded as negligible information due to edge effects. These edge effects were a result of not being able to synchronize the edge of the patterns with each GPS coordinate. The values above 50 ms, or 5%, were broke into categories of less than 25%, 25 through 49%, 50 through 74%, 75 through 99%, and continuous flow.

Data from the Detectspray system traveling at approximately 2.5 mph was transformed into an application map as shown in figure 21. Direction of travel for this map started in the east corner of the field, and proceeded northwest at a 45-degree angle to the orientation of the soybean rows. The application map shows the nozzles were activated directly over the vegetation pattern. This map also shows how nozzle 4 was recorded activating over bare soil during the test. Then, as stated earlier, the sensitivity was decreased for the entire system, and the nozzle operated correctly throughout the rest of the test.

The Weedseeker system was attached behind the Detectspray system during the tests. The data for Weedseeker was extracted from the file and used to create the application map shown in figure 22. This map displayed activation

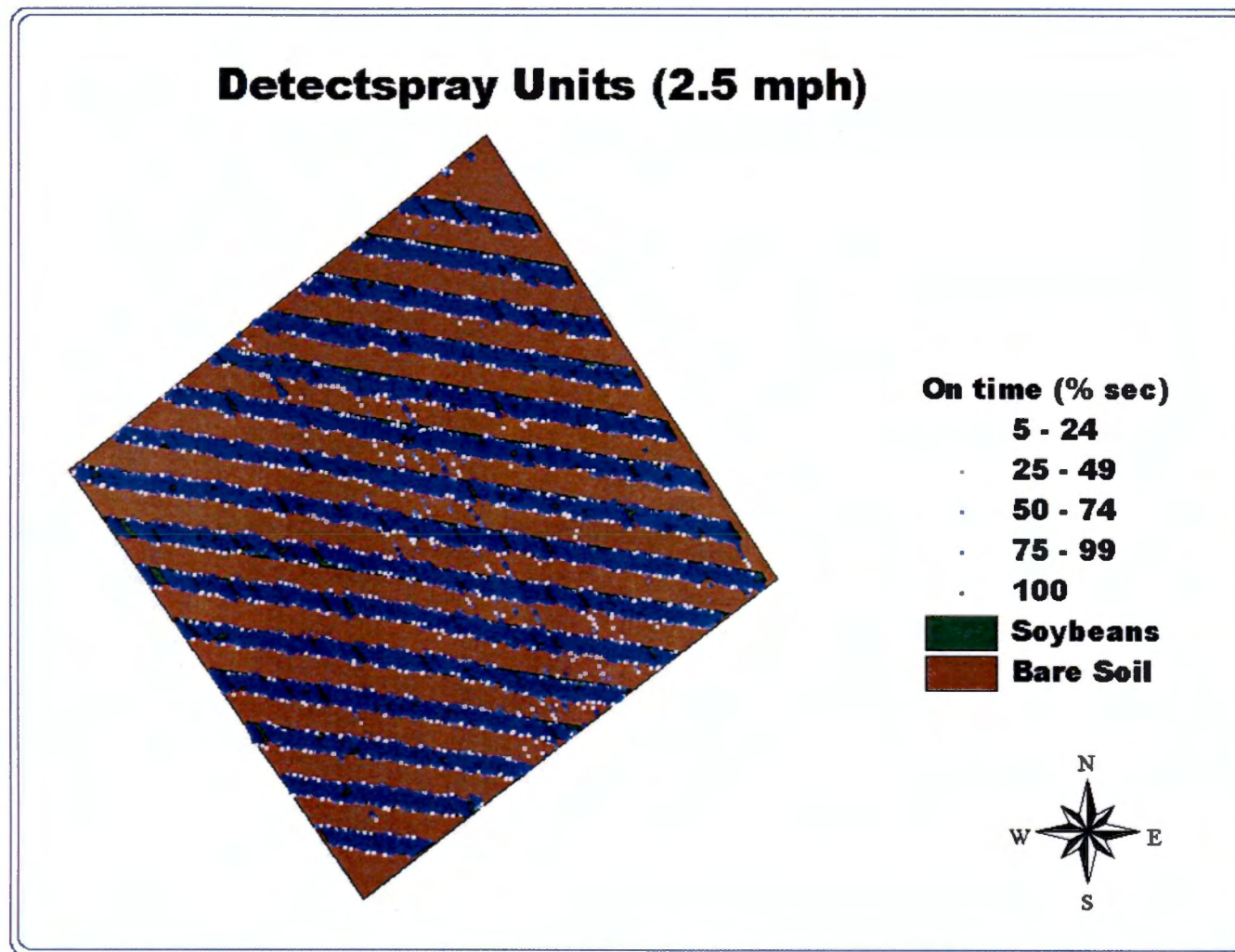


Figure 21. Application map for the Detectspray units traveling 2.5 mph during the known pattern test.

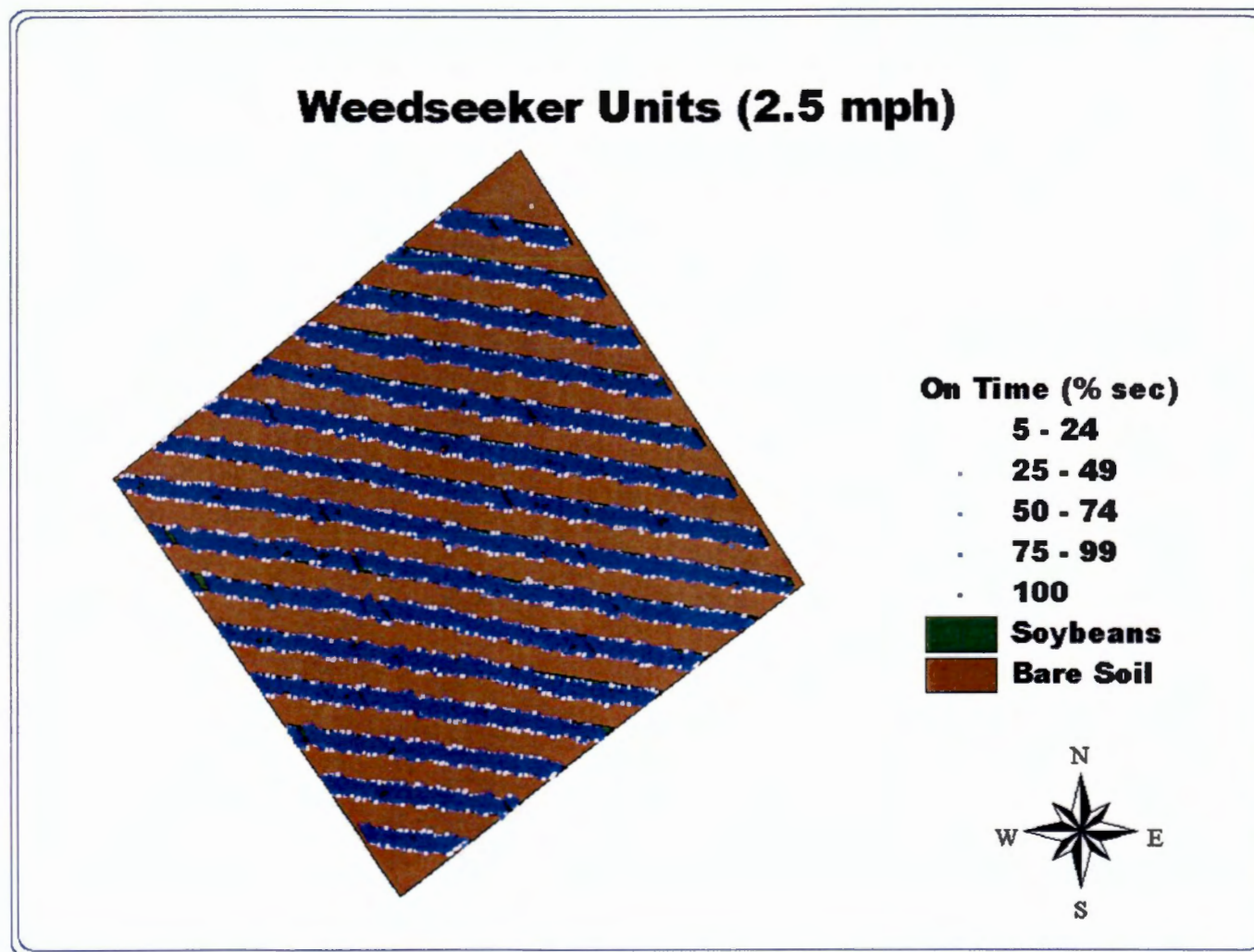


Figure 22. Application map for the Weedseeker units traveling 2.5 mph during the known pattern test.

of the units over the vegetation, and very little false activation were recorded from the Weedseeker system.

For the 5.8 data the field size was reduced due to a mechanical failure unrelated to the DAS or the sprayers. However, there was sufficient data for analysis. Application maps from Detectspray (figure 23) and Weedseeker (figure 24) show further distance between points because the sprayer was traveling more distance per recorded event. Overall the maps show that the DAS recorded the sprayers turning on over soybean rows.

C. Map Analysis

Analyses of the application maps were conducted for hits, misses, and false triggers. The purpose of this analysis was to prove that the DAS recorded activation of the sprayer units over vegetation and deactivation over soil. Blocks were created inside the soil and vegetation areas of the field to select the points completely within these boundaries. The points were then analyzed for accuracy based on the underlying theme.

Blocks were placed in the center of the vegetation and bare soil area to define areas where the sprayer should have been on or off (figure 25). The first theme called Vegetation was centered in the soybean polygons approximately 3 ft. from the edges. The second theme called Soil was centered in the bare soil area approximately 11 ft. from the vegetation polygons. This process moved the blocks inside the soil/vegetation areas to remove spatial error associated with differentially corrected GPS. In addition, this corrected edge effects occurring from the inability to synchronize a GPS coordinate with the vegetation edges.

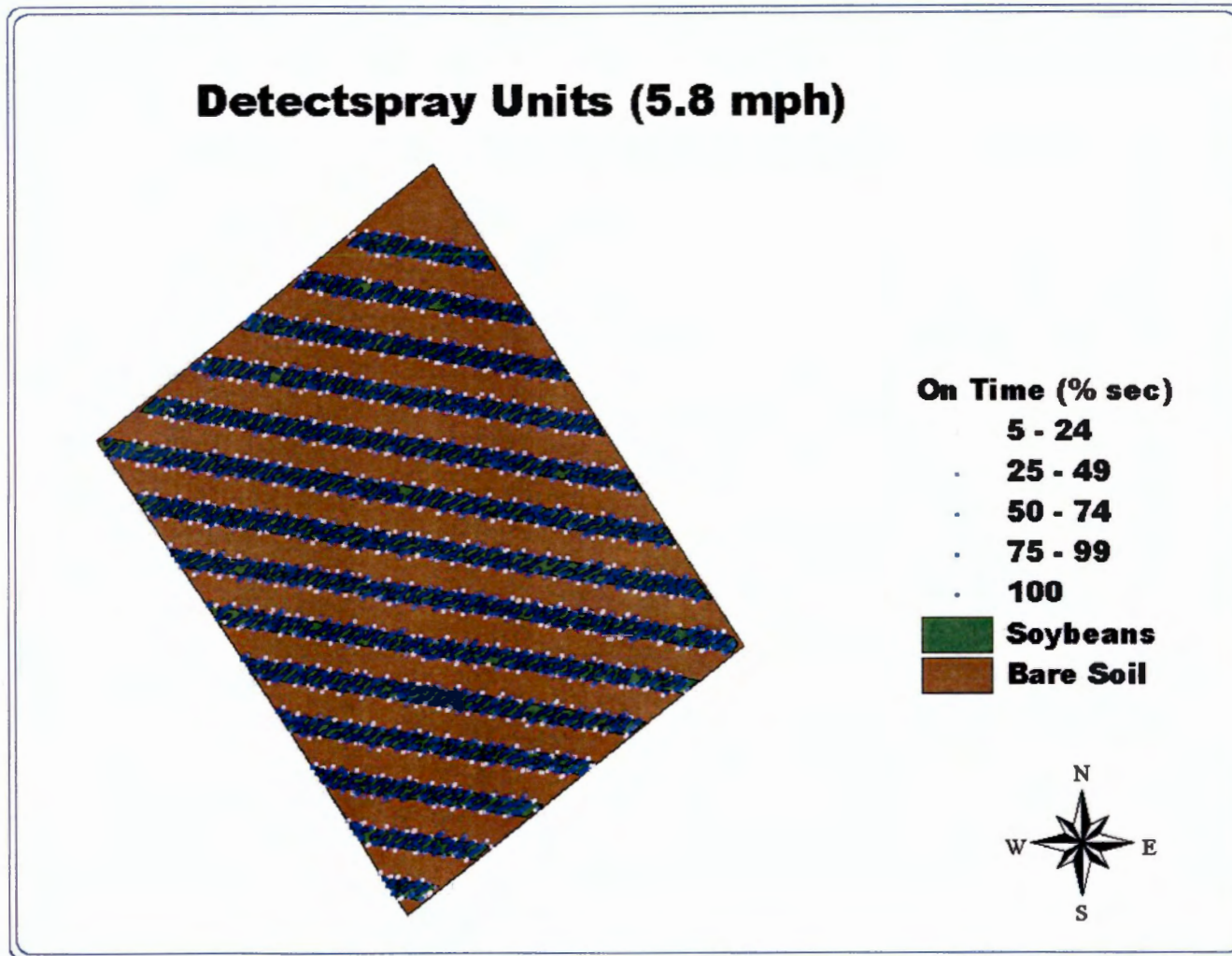


Figure 23. Application map for the Detectspray units traveling 5.8 mph during the known pattern test.

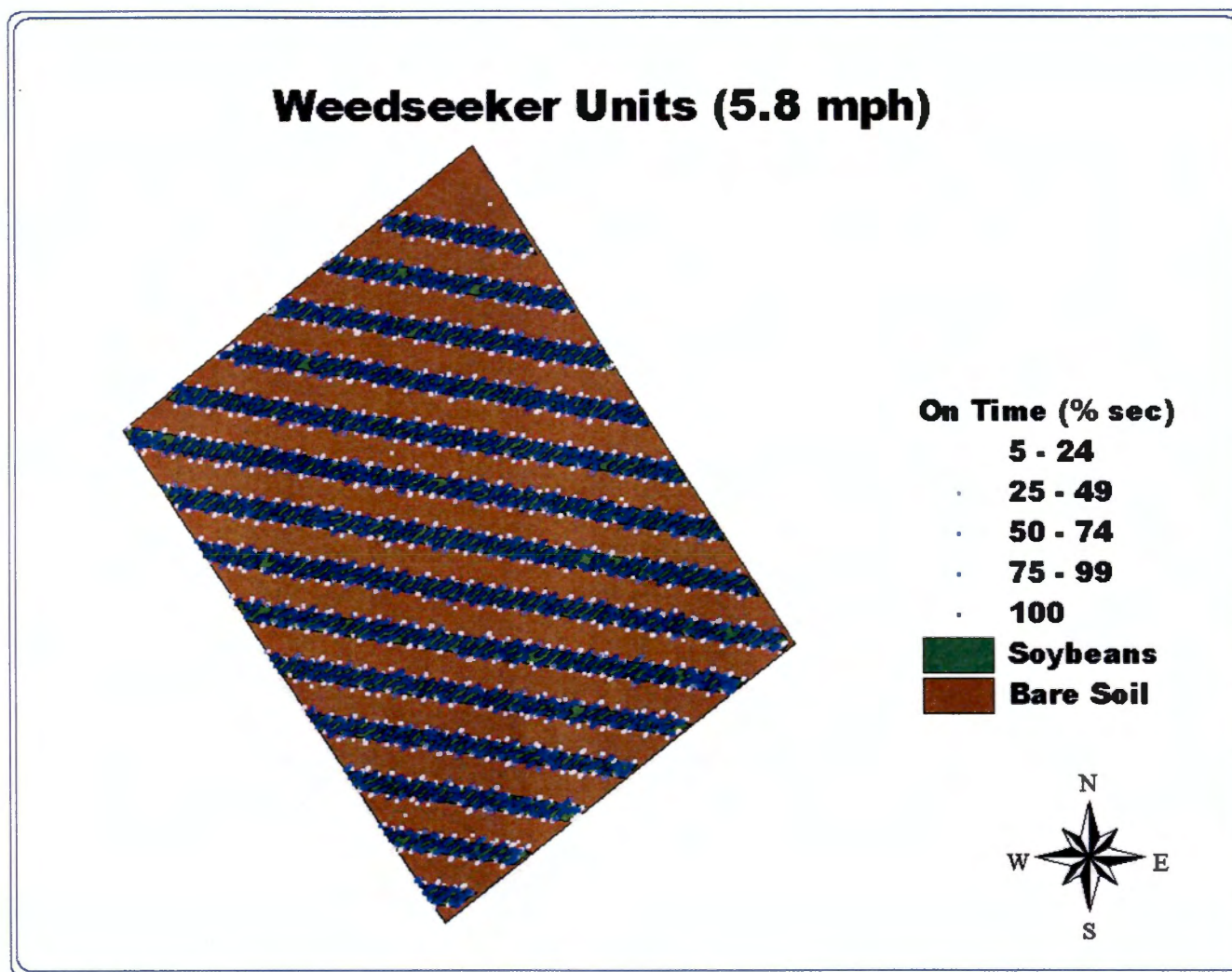


Figure 24. Application map for the Weedseeker units traveling 5.8 mph during the known pattern test.

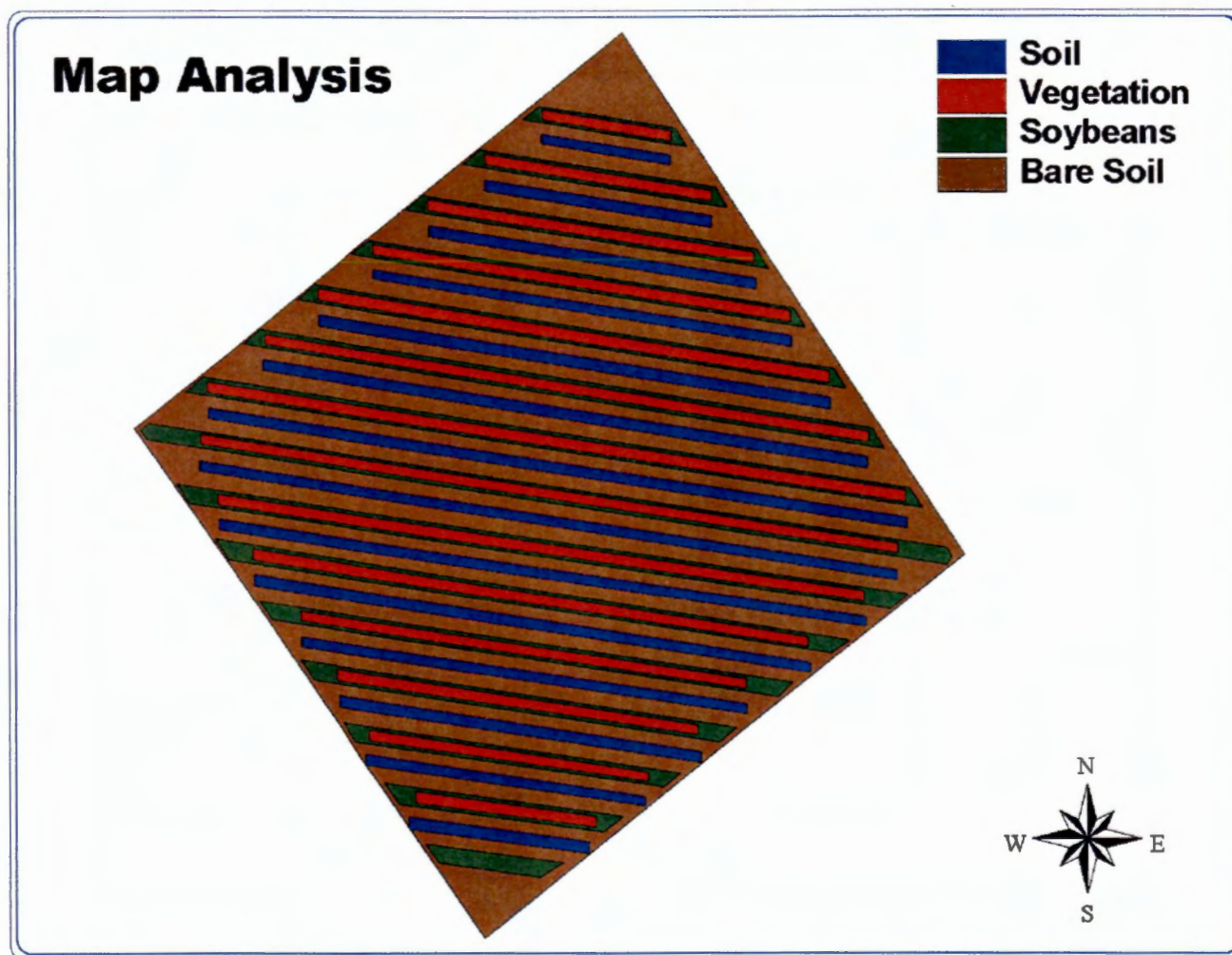


Figure 25. Soil and weed blocks were constructed to select points from the known pattern test for analysis.

These themes were used in the application maps to select the points that were completely within their boundaries. A new shape file was created for the selected points in the soil and vegetation blocks. These new shape files were examined using the theme table that contained % on for each nozzle. The table column % on inside the vegetation blocks should have been 100%, while the soil blocks should have been 0%.

To categorize hits, misses, and false triggers, these values in the vegetation and soil table were sorted in numerical order by % on. As shown in table 1 the number of points were counted within the categories of 0%, 100%, and classes ranging of 10% between. These values show how the sprayers reacted within the entire soil or vegetation blocks.

For the weed blocks 0% represents a miss, and 100% represents a hit. Values between 0 and 100% show that that the system was not fully open for a complete second. However, the amount of points that were less than 100% are negligible when compared to the total number of points within those blocks. Overall the amount of hits for the vegetation blocks was between 85 and 93%.

The soil blocks define an area where the sprayer should not have been activated. As a result, when the nozzle came on in this area it was classified as a false trigger. As noted earlier, nozzle 4 on the Detectspray system was activating over the bare soil during the slow test. This resulted in points labeled as false triggers. According to the DAS after the sensitivity was reduced the Detectspray did not have any false triggers in the fast test. In addition, the

Table 1. Data representing hits, misses, and false triggers for known vegetation cover.

	Detectspray slow		Weedseeker slow		Detectspray fast		Weedseeker fast	
% On-Time	Weed	Soil	Weed	Soil	Weed	Soil	Weed	Soil
0	32	5928	96	10787	0	2602	0	4687
1-9	12	9	26	1	0	0	0	0
10-19	12	13	37	2	1	0	0	2
20-29	15	21	48	0	0	0	0	0
30-39	31	11	64	0	1	0	1	0
40-49	37	9	87	0	1	0	4	0
50-59	51	4	109	0	4	0	12	0
60-69	63	2	129	0	13	0	21	0
70-79	63	3	145	0	22	0	34	0
80-89	94	1	222	0	41	0	99	0
90-99	107	0	313	0	81	0	233	0
100	5183	3	9646	0	2386	0	4123	0
Total	6063	6004	10922	10790	2550	2602	4527	4689
Correct	5183	5928	9646	10787	2386	2602	4123	4687
Other	518	76	1276	3	164	0	404	2
% Correct	85.48%	98.73%	88.32%	99.97%	93.57%	100.00%	91.10%	99.96%
% Other	14.52%	1.27%	11.68%	0.03%	6.43%	0.00%	8.90%	0.04%

DAS recorded that the Weedseeker units had less than three false triggers in each test, but these false triggers were recorded less than 20% on.

This analysis shows that the DAS recorded hits, misses, and false triggers. As stated previously, false triggers in the Detectspray slow test were recorded by the DAS and later mapped in ArcView. This analysis also shows that the DAS accurately recorded an activated nozzle over vegetation and a closed nozzle over soil.

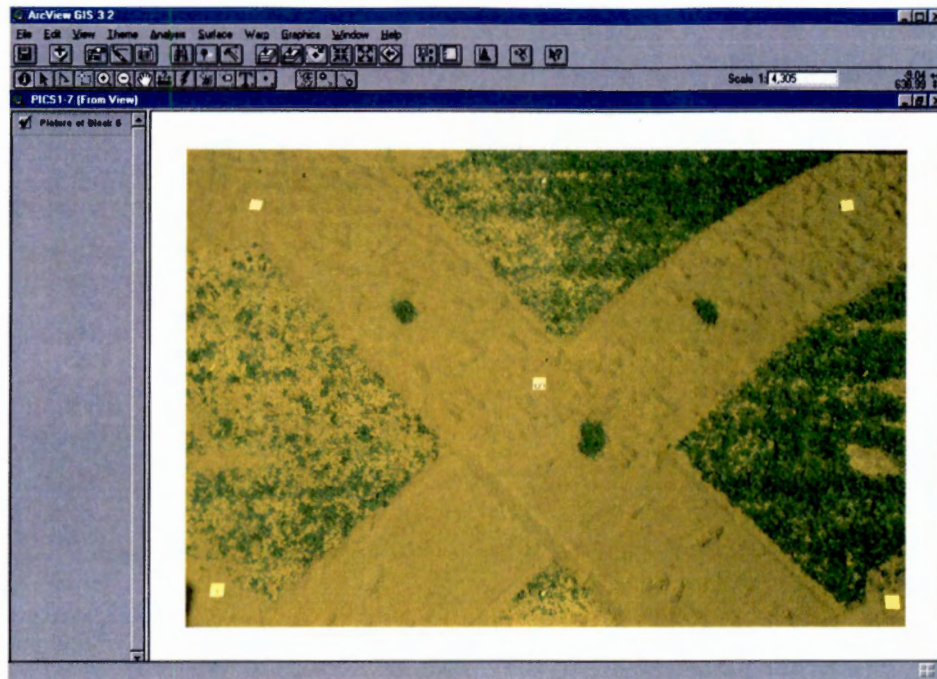
Random Vegetation Pattern

A field was setup to evaluate the DAS using a soil/vegetative pattern to generate a random discrete on/off signal from the selective-type sprayers. This experiment was designed to compare the application maps from the DAS to a vegetation map generated from remotely sensed images. To accomplish this goal, pictures were taken of the plot used in the experiment and analyzed to generate a vegetation map of the field.

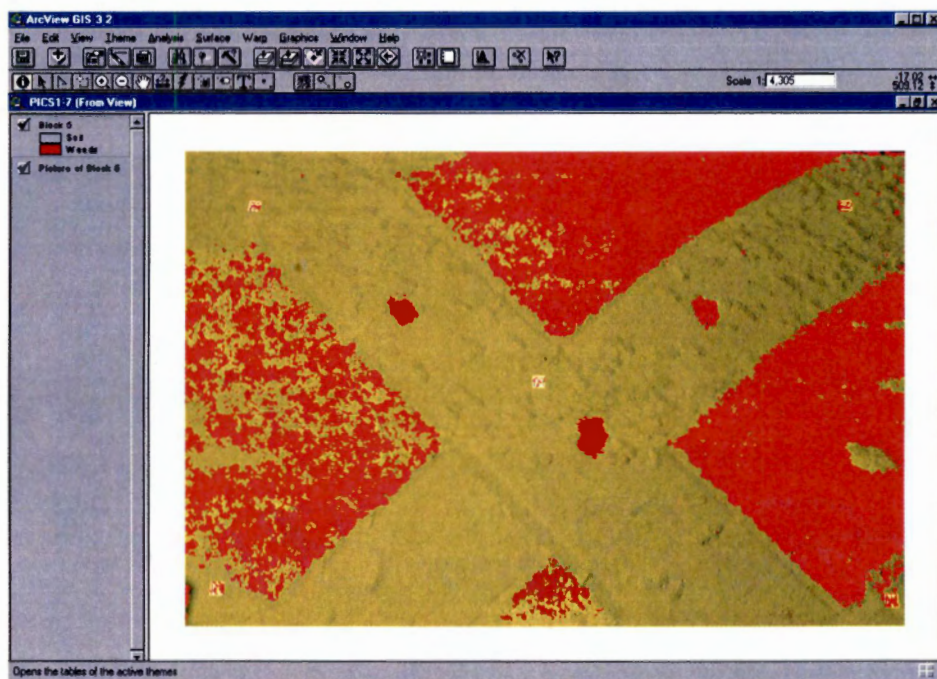
In addition, the plots in this experiment were sprayed twice with the selective sprayer systems. The first trial was conducted with the GPS output set at 1 Hz, while the second trial was conducted with the GPS output set at 2 Hz. This was to verify if the system could accurately record 2 Hz GPS input.

A. Vegetation Map

The pictures taken from the bucket truck were imported into ArcView and converted to grids. These grids were transformed into a vegetation pattern outlined by the process in chapter 4. Once this image was transformed into a vegetation pattern (figure 26) it was layered back on top of the remote image for



a. image of block 5



b. weed pattern

Figure 26. Weed pattern (b) was layered back on the image of block 5 (a) from the random pattern test to show accuracy of this grid.

analysis. Through visual observation, accuracy of the weed grid for each block proved to be correct.

These new weed grids were then warped to a geographic location from the points that were located in the photos. This created a vegetation map (figure 27) for the plot. In this vegetation map green indicate that vegetation was present in that pixel of the remote image. These green regions indicate locations where the sprayer should have been activated. In addition, this vegetation map shows areas where the field had no vegetation or was tilled to destroy the vegetation.

Due to areas that had scattered vegetation, which turned the sprayers on when there was only a small percent of that area covered by vegetation, a smoothing technique was conducted using Neighborhood Statistics in ArcView. The purpose of this function was to look at an area larger than the weed grid on the vegetation map, and then assign that area the majority value of the of the weed grid. A 3-in. x 3-in. grid cell was used on all 14 blocks. The result of this procedure was a new vegetation map that displays areas where the sprayer should have been activated. As shown in figure 28 the smoothed vegetation map-displays locations that were labeled as weed areas.

B. Application Map

Two application maps were made for both spray systems to display the 1 and 2 Hz input from the GPS. These maps prove that the system could be used with either frequency. However, the increased rate of GPS input doubled the DAS data file size, but reduced the distance between GPS coordinates.

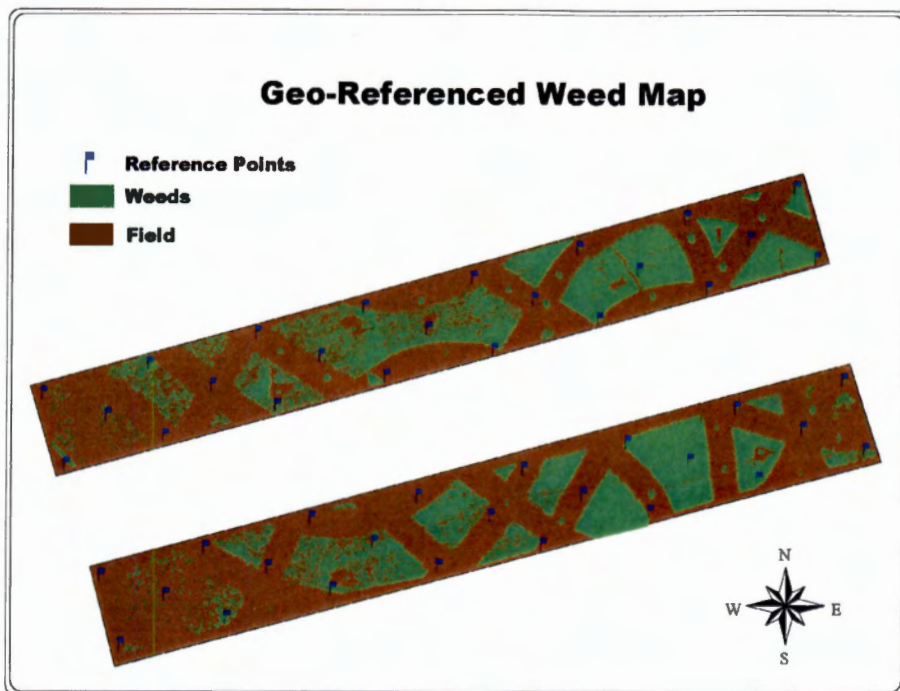


Figure 27. Geo-referenced vegetation map from random pattern test displayed true vegetation location.

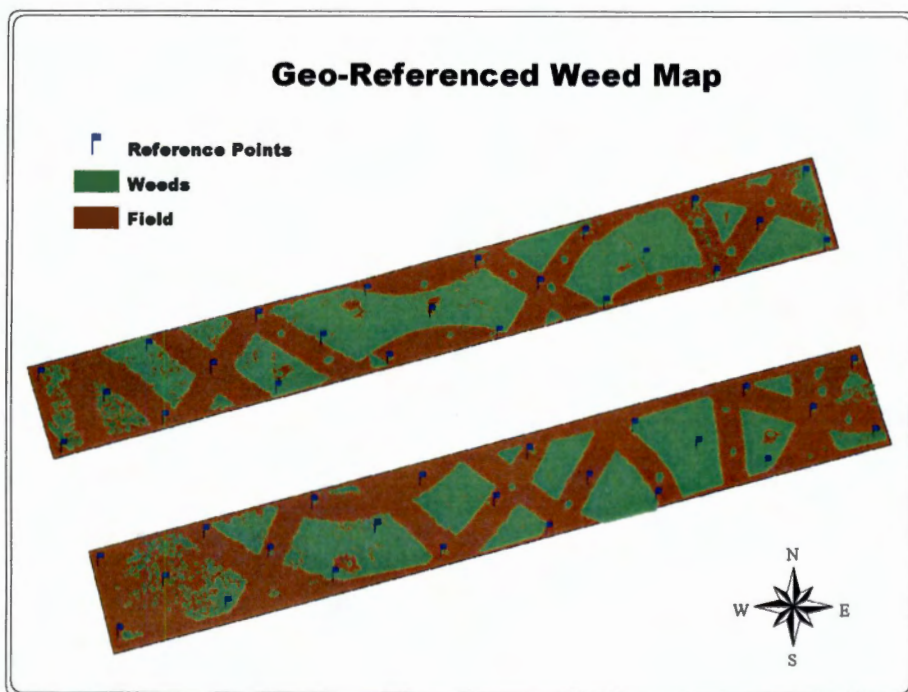


Figure 28. Smoothed vegetation map from random pattern test displayed where the sprayer should have activated.

Speed for the entire system was held constant at approximately 2 mph throughout both experiments. Remaining at the same speed for the experiment doubled the amount of points that covered the test plot for the 2 Hz input rate. On the other hand, when input rate was set at 2 Hz, distance covered for each GPS point was reduced by half compared to the 1 Hz input rate.

When the maps were generated, a background shape file was created to represent the layout of the field. This file was based on the geographic points that marked each block in the field. Then the data files were added to the view once the data had been transformed into a text file. This sprayer theme was displayed as a graduated color based on the percent on column that represented the amount of time the nozzles were on for the record period.

An application map for Detectspray at 1 Hz input rate was generated in ArcView (figure 29). This map reports referencing nozzle status with a GPS signal as proven by the known vegetation pattern test conducted at Milan Experiment Station. The graduated color theme shown in the map was classified from the data file column percent on.

As shown in figure 30, the application map from Detectspray at 2 Hz GPS input reported the same activity as the 1 Hz input. Application maps from Weedseeker had similar results; the 1 Hz data (figure 31) matches with the 2 Hz data (figure 32). The maps from both units displayed no problem using either input frequency to generate an application of the system.

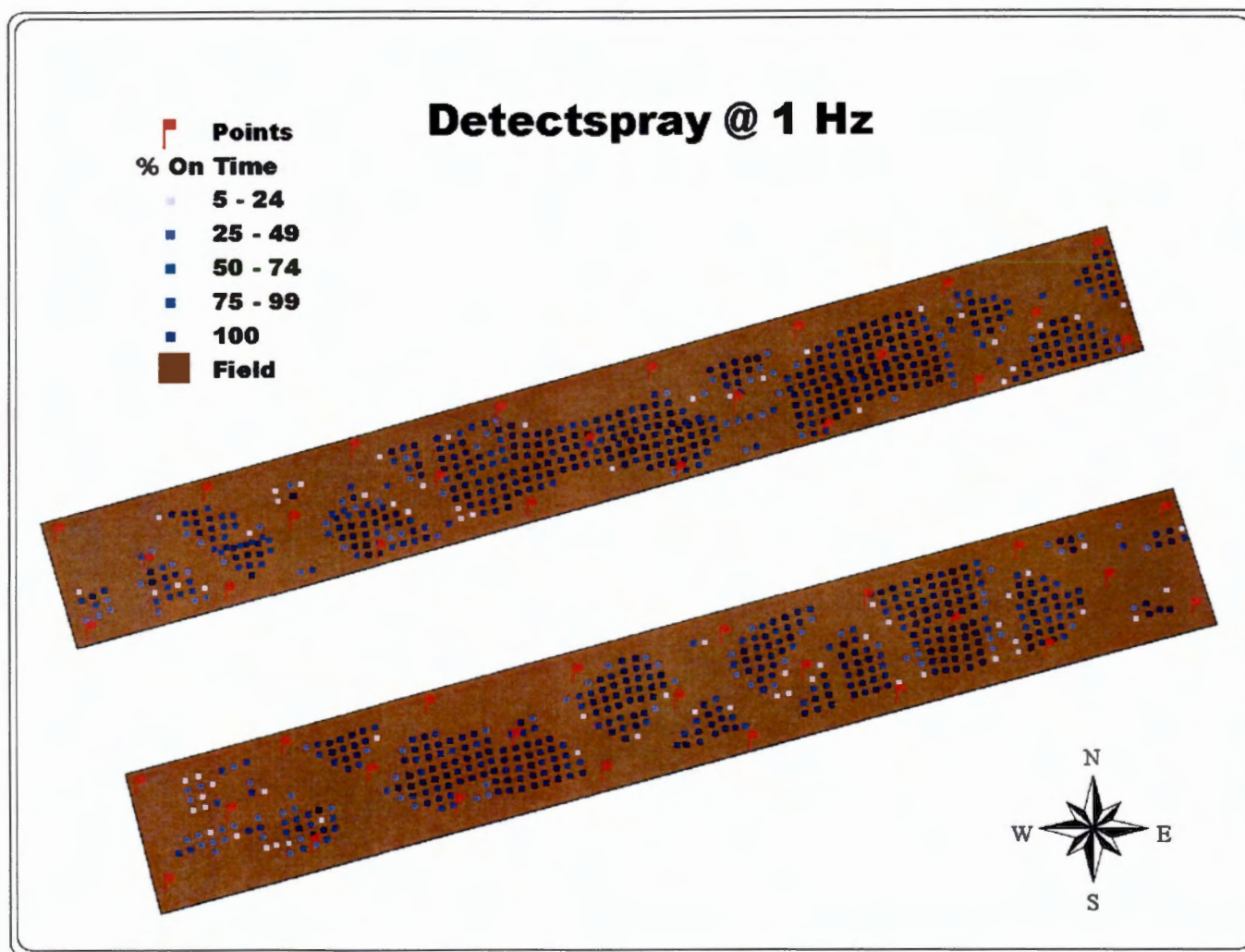


Figure 29. Detectspray application map for random pattern field test with GPS input set at 1 Hz.

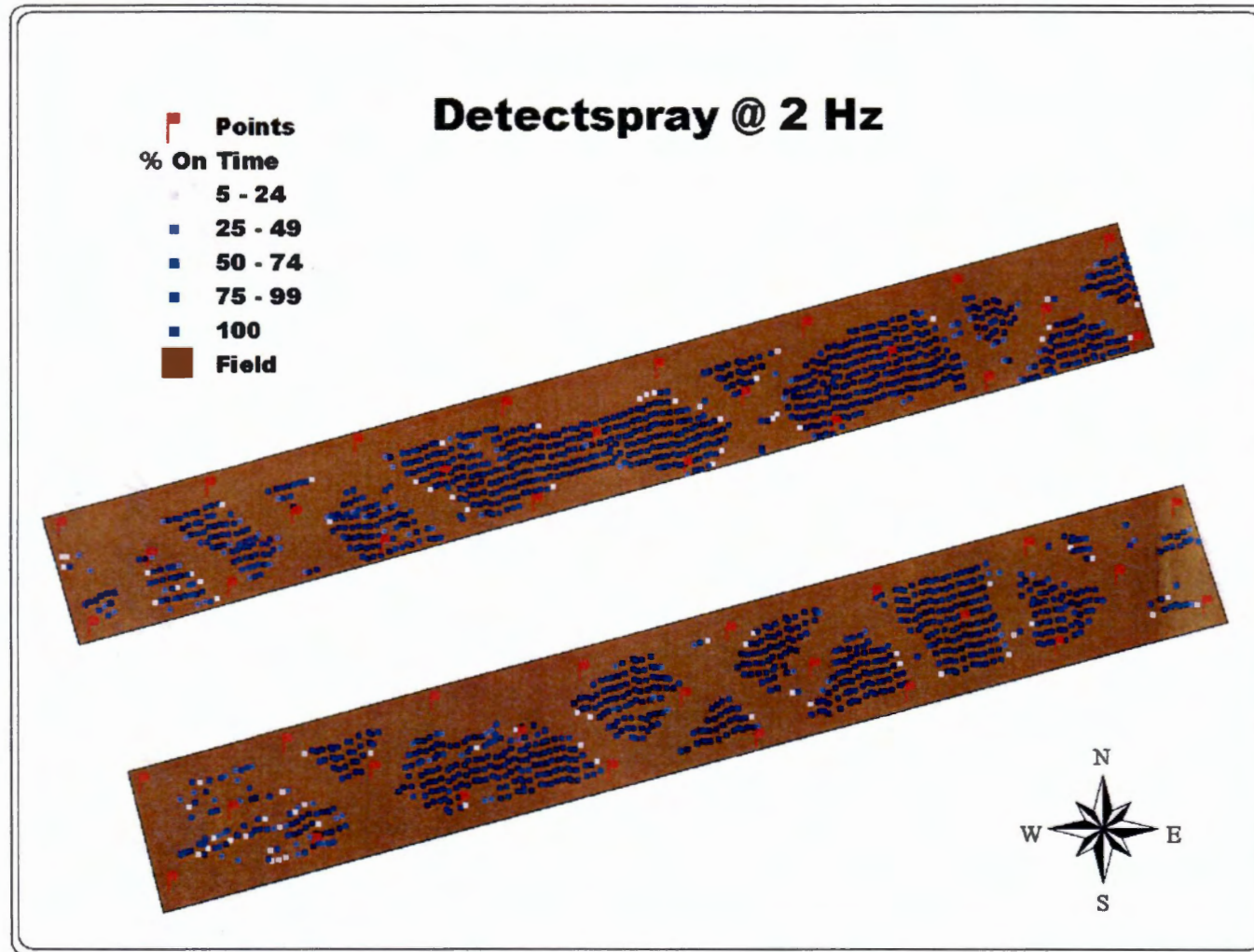


Figure 30. Detectspray application map for random pattern field test with GPS input set at 2 Hz.

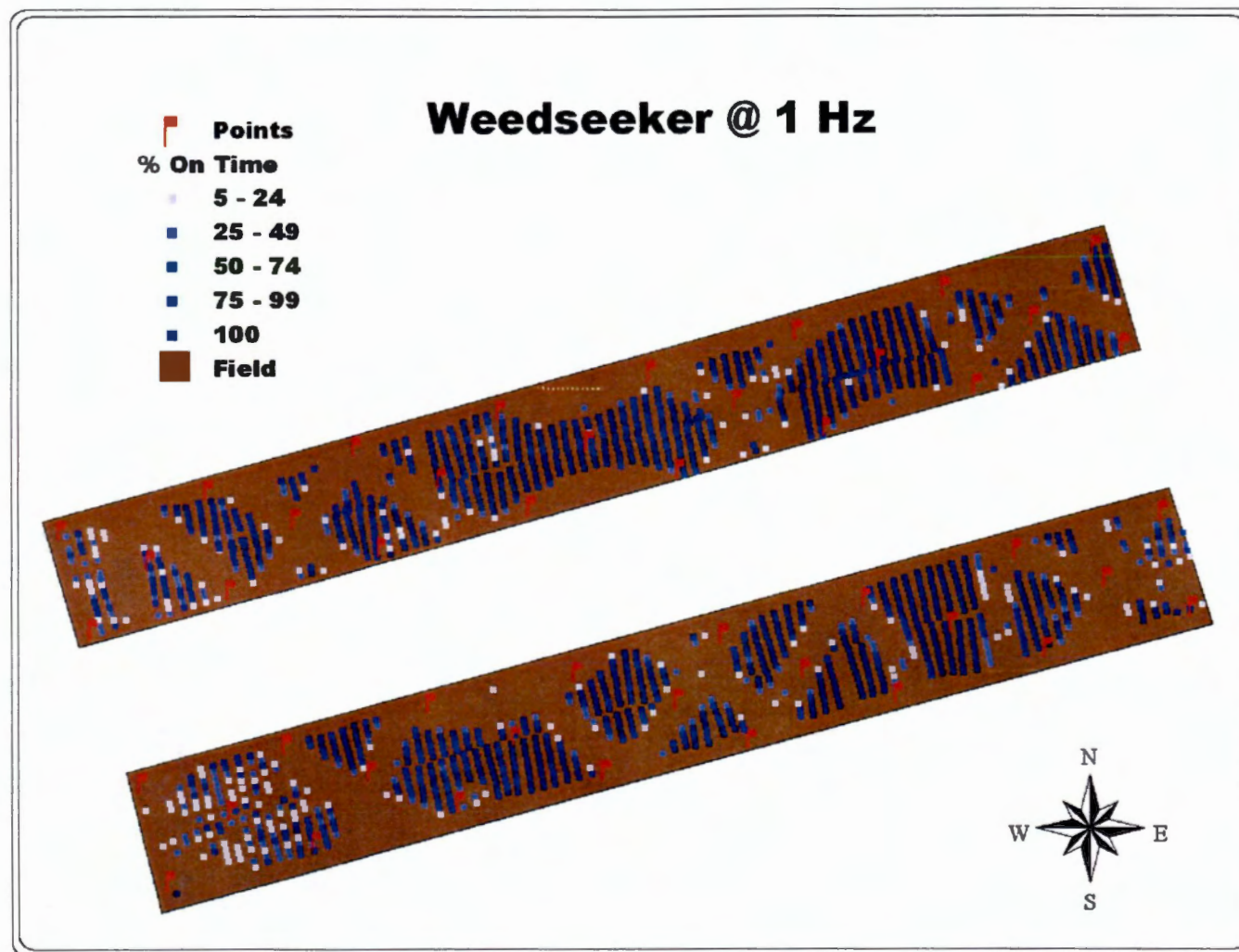


Figure 31. Weedseeker application map for random pattern field test with GPS input set at 1 Hz.

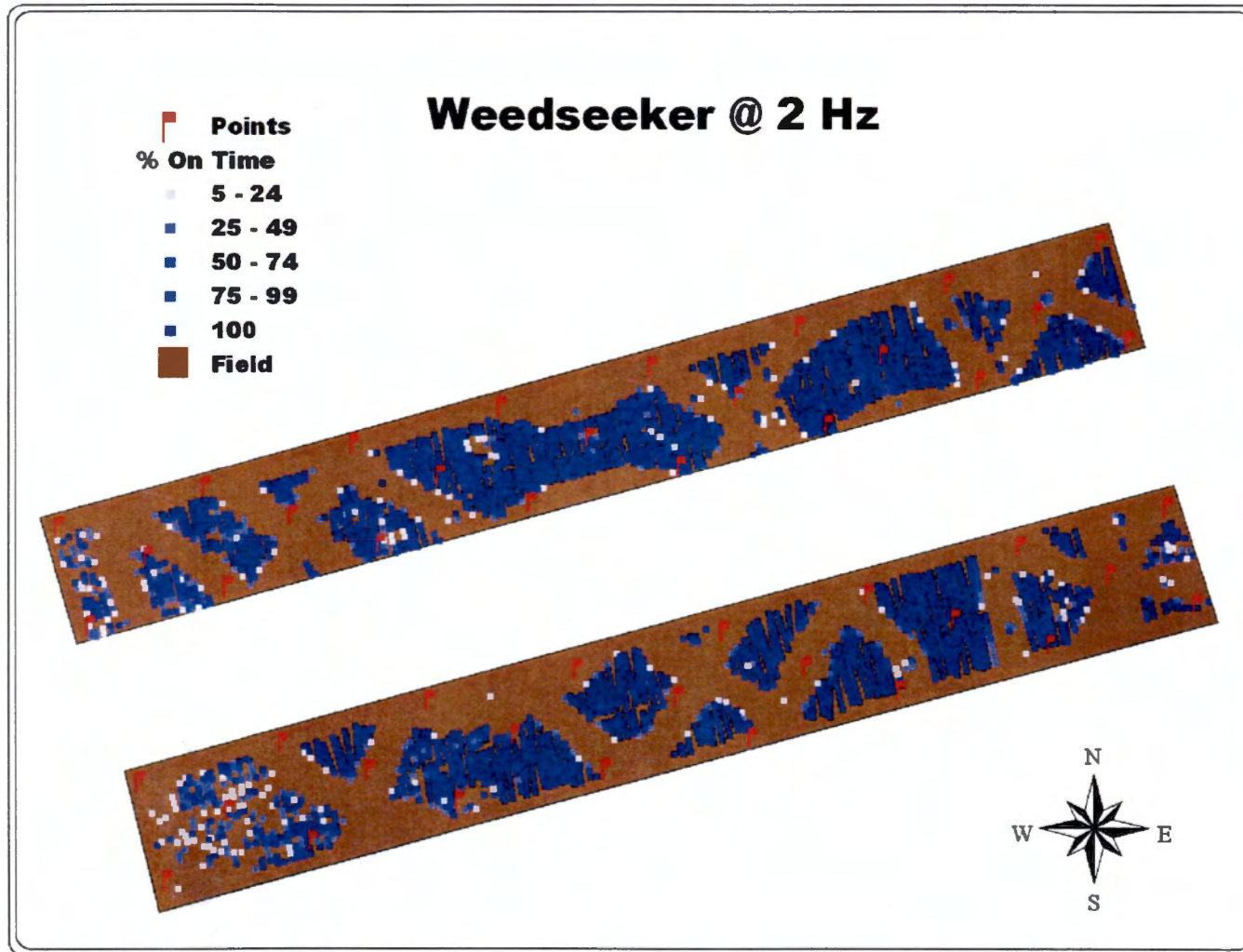


Figure 32. Weedseeker application map for random pattern field test with GPS input set at 2 Hz.

C. Map Comparison

The application maps and vegetation map were analyzed for comparison. The pattern of areas with and without vegetation was identified on both maps and visually agrees with each other. However, further observation determined slight differences in geographic locations between the maps. This test was conducted using differentially corrected GPS (DGPS), which has submeter accuracy. All point data in the application maps and the vegetation map were within this submeter accuracy. Therefore, analysis conducted on these maps accounted for this error by looking at locations inside definite vegetation or no vegetation areas.

Map areas inside large vegetation patterns and large soil areas were selected for analysis (figure 33). A polygon was created for each of the areas to select features of the sprayer theme that were completely within a weed or soil block. This process removed most of the error associated with DGPS and edge effects as stated earlier.

These areas were evaluated using the theme table to verify the on or off status. Each of the sprayer tests proved to be successful in recording nozzle activation over the vegetation blocks, and deactivation over the soil blocks. As shown in table 2, the number of points was counted within the categories of 0%, 100%, and classes ranging of 10% between. These values show how the sprayers reacted within the entire soil or vegetation blocks. Overall the amount of hits for the vegetation blocks was between 87 and 98%, and 94 to 99% for the soil blocks.

Map Analysis

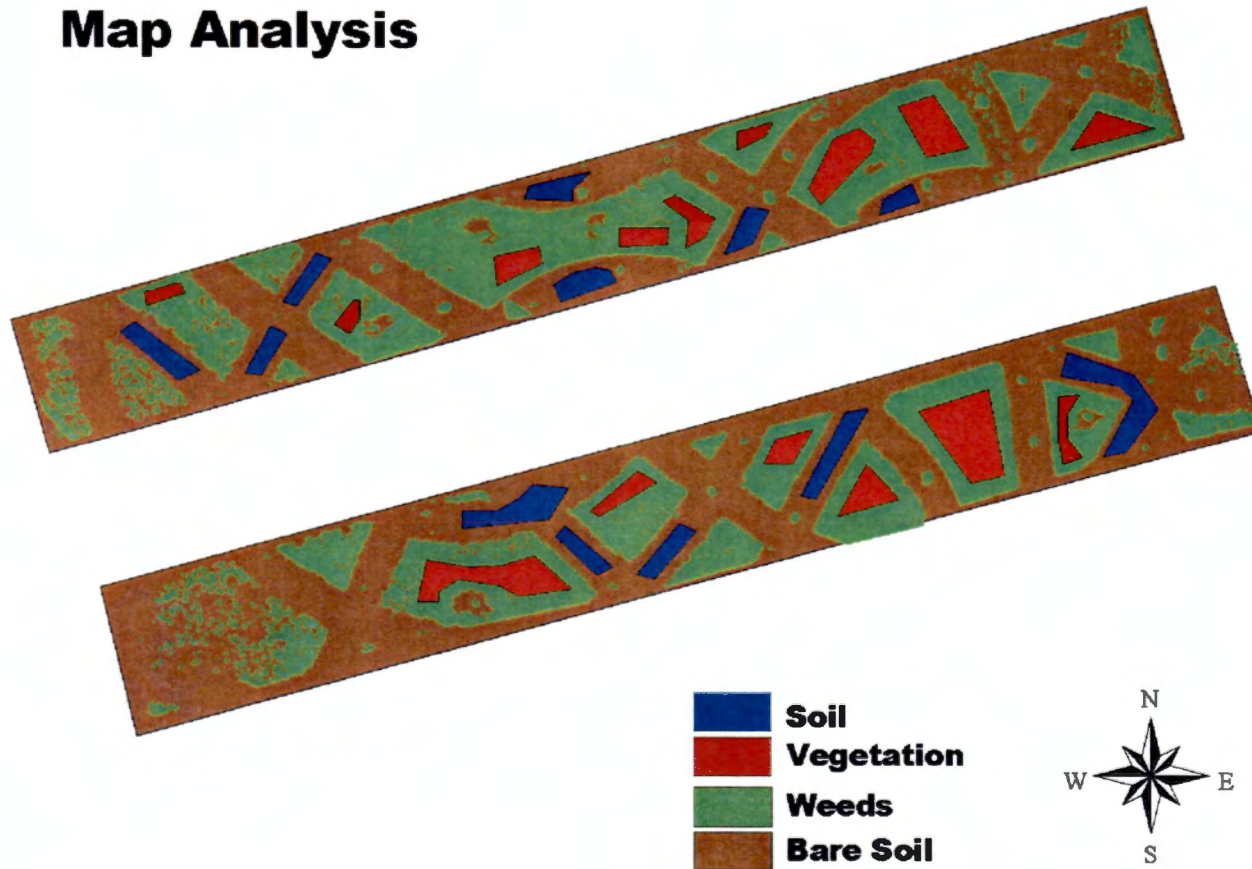


Figure 33. Soil and vegetation blocks were constructed to select points from random pattern test for analysis.

Table 2. Data representing hits, misses, and false triggers for random vegetation cover test.

	Detectspray 1 Hz		Weedseeker 1 Hz		Detectspray 2 Hz		Weedseeker 2 Hz	
% On-Time	Weed	Soil	Weed	Soil	Weed	Soil	Weed	Soil
0	0	91	0	163	1	183	1	317
1-9	0	1	0	1	0	0	2	3
10-19	0	1	0	0	0	1	1	1
20-29	0	1	1	0	0	0	1	0
30-39	0	1	0	0	1	1	0	1
40-49	0	0	0	0	1	1	2	1
50-59	0	0	1	0	1	0	1	2
60-69	0	0	0	0	1	1	5	0
70-79	1	0	7	0	1	1	6	1
80-89	1	0	6	0	5	0	22	1
90-99	4	0	16	0	1	0	20	0
100	153	0	224	0	288	0	463	9
Total	156	95	255	164	300	188	524	336
Correct	153	91	224	163	288	183	463	317
Other	6	4	31	1	12	5	61	19
% Correct	98.10%	95.79%	87.84%	99.39%	96.00%	97.34%	88.36%	94.35%
% Other	1.90%	4.21%	12.16%	0.61%	4.00%	2.66%	11.64%	5.65%

2. Volumetric Evaluation

Information recorded by the DAS was important for generating an application map. This test was conducted to determine the relationship between what the DAS recorded and percent volume of continuous flow for the nozzles. To accomplish this, an artificial activation device was used to activate the Detectspray system. System pressure and activation frequency remained constant while the solenoid on time was varied. Fluid was collected from two nozzles and then compared to the DAS records of each event.

Times used to activate the nozzles were selected based on reaction of the system to the AADs. As shown in table 3 column 1, the on time began at 1000 ms. This represented continuous flow because the frequency was set at 1 Hz. Differences in the on time were smaller during the outermost time spectrum to depict action of the system during the outer operating extreme conditions.

The flow rate in table 3 for each nozzle was converted to a percent flow as shown in table 4. These values represent flow rate as a percent of the continuous flow for a TeeJet 8002 flat fan nozzle. The values for nozzles 1 and 2 are displayed in columns 1 and 4 respectively.

Files used to generate these tables were recorded by the DAS representing 60 seconds of data. Data was averaged over this record period to calculate the average percent on for each nozzle. Columns 2 and 5 in table 4 report these values for comparison to the actual percent flow. Differences between measured and recorded values are shown in table 4 columns 3 and 6. Total absolute difference for nozzle 1 was 1.7%, and 2.3% for nozzle 2.

Table 3. Flow was collected for each on time from each nozzle during the volumetric evaluation.

On Time (ms)	On Time (%)	Nozzle1 (ml/sec)	Nozzle 2 (ml/sec)
1000	100.0	13.0	12.8
900	90.0	12.3	12.1
850	85.0	12.5	12.6
820	82.0	12.9	12.8
810	81.0	12.5	12.5
800	80.0	12.6	12.7
790	79.0	11.9	11.9
750	75.0	11.6	11.6
700	70.0	10.8	11.0
600	60.0	9.5	9.5
500	50.0	8.5	8.6
400	40.0	7.1	7.2
300	30.0	6.1	6.2
200	20.0	4.8	4.9
150	15.0	4.1	4.3
125	12.5	3.9	3.9
100	10.0	3.5	3.5
85	8.5	3.2	3.3
75	7.5	3.1	3.2
65	6.5	3.0	3.0
55	5.5	2.9	3.0
45	4.5	2.6	2.8
35	3.5	1.5	2.7
25	2.5	1.3	2.5
15	1.5	1.6	2.4
10	1.0	1.9	2.4
5	0.5	2.1	2.3
2	0.2	1.1	1.4

Table 4. Nozzle flow rates comparing measured flow and recorded flow for the volumetric evaluation.

Nozzle 1			Nozzle 2		
Measured % Cont. Q	Recorded DAS %	Absolute Difference	Measured % Cont. Q	Recorded DAS %	Absolute Difference
100%	100%	0.00%	100%	100%	0.00%
94%	100%	5.64%	95%	100%	5.21%
96%	100%	3.24%	98%	100%	1.55%
99%	96%	3.20%	100%	97%	3.40%
96%	96%	0.26%	98%	96%	2.08%
97%	95%	2.19%	99%	95%	3.84%
91%	94%	2.22%	93%	94%	0.60%
89%	90%	0.64%	91%	90%	0.42%
83%	84%	1.09%	86%	84%	1.49%
73%	75%	2.20%	74%	75%	0.95%
66%	65%	0.57%	67%	66%	1.64%
55%	54%	1.31%	56%	54%	2.42%
47%	44%	2.76%	48%	45%	3.65%
37%	34%	2.56%	39%	35%	3.84%
32%	30%	2.14%	33%	30%	3.38%
30%	29%	1.21%	31%	29%	1.85%
27%	25%	1.57%	28%	25%	2.20%
25%	23%	2.09%	26%	23%	3.03%
24%	22%	1.70%	25%	22%	2.56%
23%	21%	1.97%	23%	21%	2.27%
23%	21%	1.78%	23%	21%	2.52%
20%	17%	2.29%	22%	19%	2.23%
11%	11%	0.47%	21%	18%	2.90%
10%	11%	0.29%	20%	17%	2.38%
13%	11%	1.68%	19%	16%	2.78%
15%	13%	1.54%	19%	16%	2.77%
16%	14%	2.19%	18%	15%	3.14%
8%	7%	1.51%	11%	9%	1.92%
0%	0%	0.00%	0%	0%	0.00%

Recorded percent values were plotted against measured percent values (figure 34). Both nozzles showed a linear relationship between actual and recorded values. Nozzle 1 had a slope of 0.9988 with an r^2 of 0.9964, and nozzle 2 had a slope of 1.0146 with an r^2 of 0.9948. This shows that the values recorded by the DAS are related to actual conditions.

Using the DAS as truth, the difference between recorded and measured values were calculated and plotted. The error from the truth for nozzle 1 and 2 are shown in figure 35 and 36 respectively. These graphs show nozzle 1 and 2 had approximately the same error trend, with their highest positive value occurring when the DAS recorded 44% for nozzle 1 and 35% for nozzle 2. However, not a large amount of error was measured with the highest being less than 6%.

Operation of the solenoid caused a change in flow and spray pattern through the nozzle between 95% and 100% as observed in figure 34. This phenomenon is known as electrical inertia. The magnetic field created to open the solenoid requires a certain amount of time to dissipate once current flow through the coil is discontinued. When the solenoid is turned off by the sensor it is held open by the magnetic field, which allows more flow to pass through the nozzle than what is being recorded by the DAS. In addition, the sprayer system pressure rises when the nozzles closed. When they are opened, the higher pressure produces a higher flow until original settings are achieved.

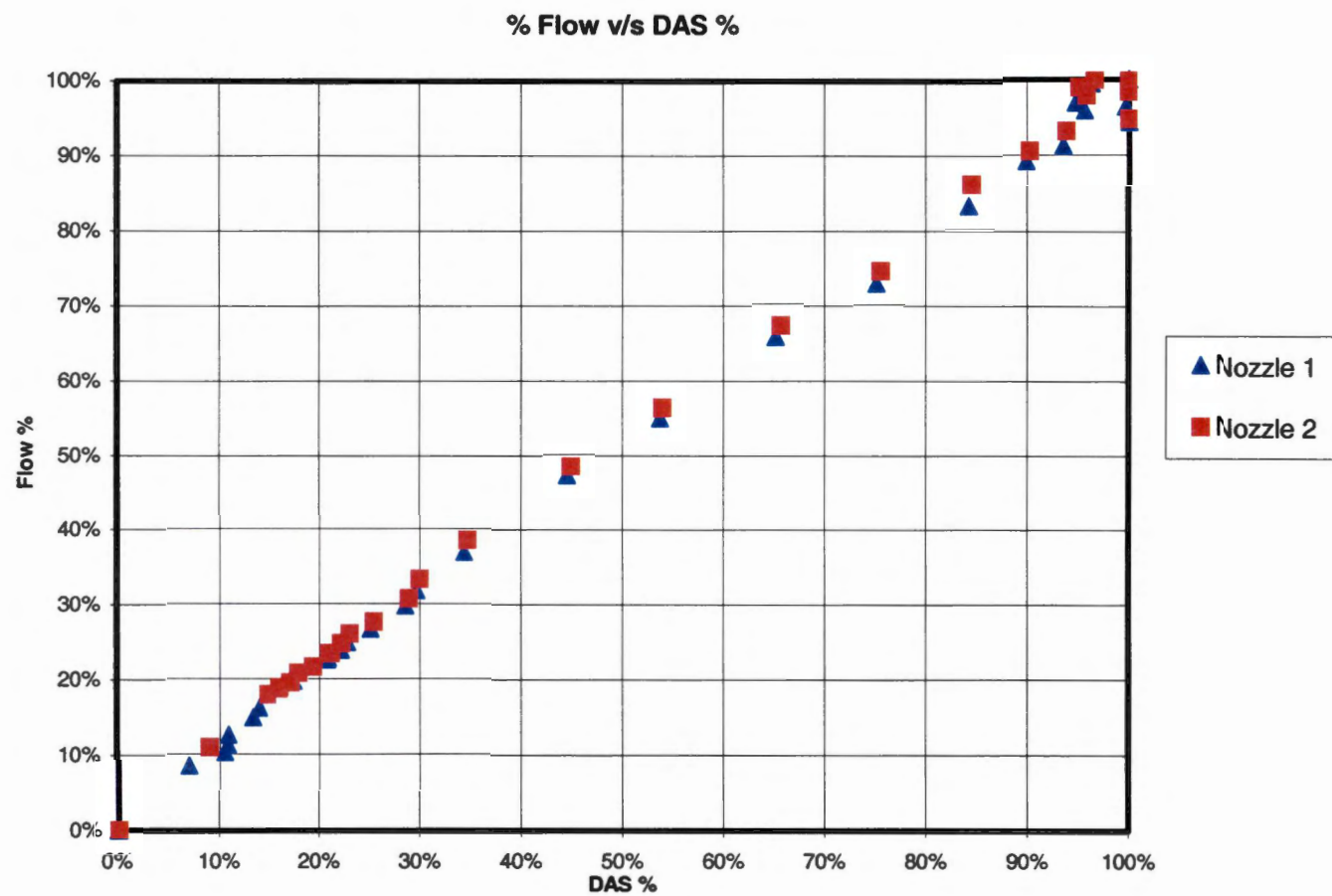


Figure 34. Recorded DAS % v/s measured flow % for the volumetric test displays a high linear relationship between the actual % and recorded %.

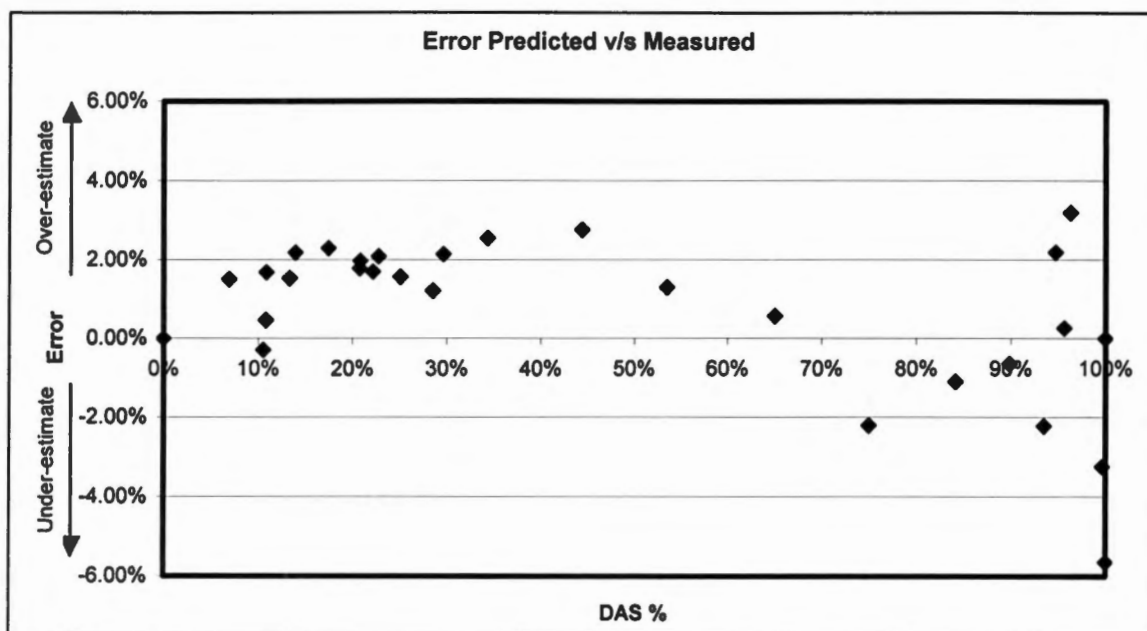


Figure 35. Error for nozzle 1 using the DAS as truth for the volumetric test displays how the nozzle reacted.

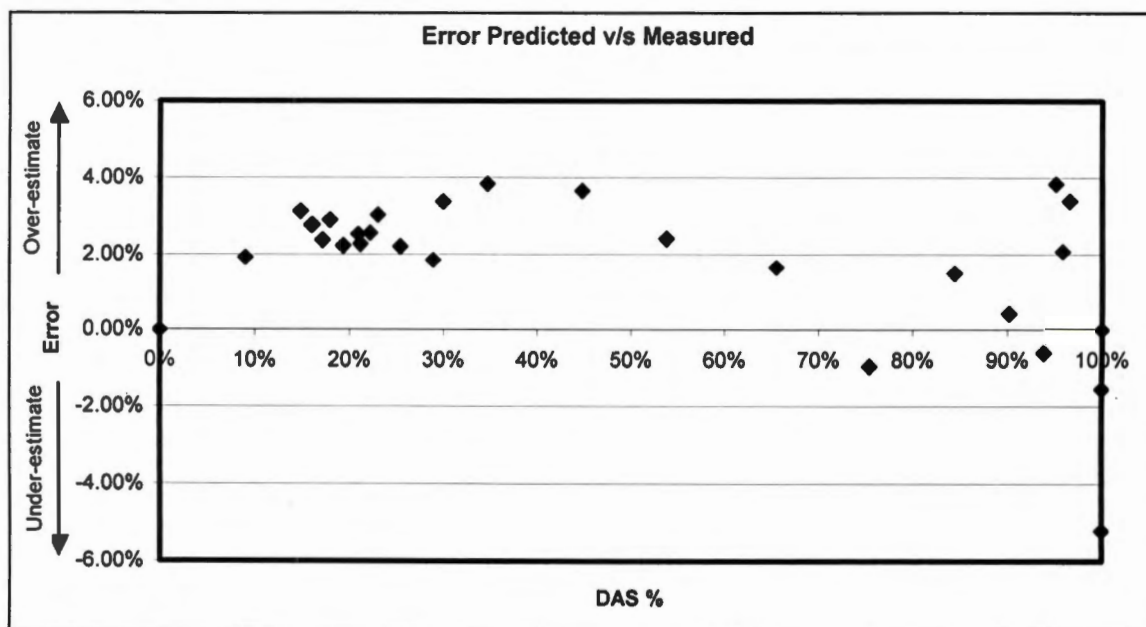


Figure 36. Error for nozzle 2 using the DAS as truth for the volumetric test shows how the nozzle reacted.

CHAPTER V

SUMMARY AND CONCLUSIONS

1. Summary

A DAS was developed by the ABE department at The University of Tennessee to record and combine the nozzle status of two selective-type sprayers with a GPS signal. This recorded data was imported to ArcView GIS 3.2 where an application map was generated and then analyzed. In further studies a plot with random weed coverage was designed to operate the selective-type sprayer, and take remote images of blocks created within the plot. These remote images were transformed into a vegetation map used for analyzing the application maps.

To develop this DAS, a single board computer was housed in a fiberglass box along with a PCMCIA card as the storage medium. An interface was necessary between the selective spray systems and DAS that consisted mainly of opto-isolators. This was required to optically isolate the two systems and convert the 12-Vdc analog signals to 5-Vdc digital signals that were usable by the DAS. The other input needed by the DAS was a GPS signal that was provided by a Trimble AgGPS 132 receiver.

To field test the system, two experiments were conducted. The first test used a defined vegetation/soil pattern to generate a distinct on/off signal for the sprayer systems. This test was performed twice with each test having a different

speed: 2.5 mph and 5.8 mph. An application map was generated for each system and speed, and then analyzed for hits, misses, and false triggers. This test proved that the DAS recorded activity of the sprayer systems for both speeds accurately with mostly 100% on over the vegetation and 0% on over the soil.

The second field test used a plot where vegetation was allowed to grow at random. Then to assure a distinct off signal to the sprayer system, a three-point hitch rotary tiller was used to destroy areas of vegetation in the field at random. In this test, blocks were setup in the plot and photographed from a bucket truck. These blocks were sprayed twice using the selective-type sprayer systems and the DAS with the GPS output set at 1 Hz for the first trial and 2 Hz for the second trial. Images taken of the blocks were used to create a vegetation map in ArcView for comparison to the application maps derived from the DAS. This test proved that both GPS frequencies could be used by the DAS, and the application map from the DAS was comparable to a vegetation map derived from the remote images.

A volumetric evaluation was conducted to verify what was recorded by the DAS. The Detectspray was artificially activated for specified times where fluid was collected and then compared to the DAS record for each trial. Over time the relationship between actual % flow and recorded % proved to be linear. This proved the DAS recorded percent volume the selective-type sprayer nozzles dispersed.

2. Conclusions

1. Nozzle status of the selective-type sprayer systems was recorded by the DAS and referenced with a GPS signal. This data was successfully recorded to the PCMCIA card as the storage medium.
2. The DAS recorded individual activation for each of the five Detectspray solenoids and nine Weedseeker solenoids.
3. Accurate application maps for the selective-type sprayers were generated in ArcView from data recorded by the DAS that was transformed by the convert program, CONV6.EXE, into a text file.
4. Increasing application speed from 2.5 mph to 5.8 mph did not decrease the ability of the DAS to record nozzle status.
5. The DAS successfully recorded nozzle status with the GPS input signal set at 1 Hz and then at 2 Hz.
6. Vegetation maps were derived in ArcView from the remote images taken from the experiment conducted at Knoxville Experiment Station.
7. Application maps derived from the DAS were comparable to vegetation maps transformed from remote images in ArcView.
8. The volumetric test proved percent of continuous flow from a given nozzle was directly related to percent recorded by the DAS.

3. Recommendations

The DAS developed by the ABE department at The University of Tennessee was developed to record an on/off signal associated with site-specific

farming. To achieve this on/off signal two selective-type sprayers, Detectspray and Weedseeker, were used. These sprayer systems were mounted in a broadcast position, which is commonly seen with selective-type sprayers used for fallow farming. Due to other setups of selective-type sprayers and other types of site-specific equipment, it is recommended that further research be conducted with this DAS to validate its versatility for site-specific agriculture.

Another setup used with a selective-type sprayer system was developed to incorporate the Weedseeker system in a hooded sprayer commonly used for row crops. Based on the research conducted with this DAS, it would prove valuable to record geographically the activity of spray units throughout a row crop field. Therefore, testing the DAS with a selective-type sprayer system mounted in a hooded sprayer is recommended.

Other types of discrete site-specific farming that were available are listed in the literature. These techniques included applications of herbicide, fertilizer, seeding, tillage, insecticide, and plant growth regulators. Techniques conducted in real time need a record of application. Therefore, testing the DAS with other site-specific farming techniques is recommended.

Due to increased usage of site-specific farming additional tools are needed for management decisions. Research conducted to develop the DAS was a step to develop such a tool. This research was successful in recording the data required to generate application maps for two selective-type sprayers. When tested and validated with other site-specific farming techniques this DAS would provide a necessary tool for increased productivity of modern agriculture.

BIBLIOGRAPHY

BIBLIOGRAPHY

- Ahrens, W.H. 1994. Relative Costs of a Weed-Activated Versus Conventional Sprayer in Northern Great Plains Fallow. *Weed Technology*. 8:50-57.
- Al-Gaadi, K.A. and P.D. Ayers. 1999. Integrating GIS and GPS into a Spatially Variable Rate Herbicide Application System. *Applied Engineering in Agriculture*. 15(4):255-262.
- Batte, M.T. 2000. Factors Influencing the Profitability of Precision Farming Systems. *Journal of Soil and Water Conservation*. 55(1):12-18.
- Beck, J.L and M.L. Kinter. 1998. Agricultural Implement Having Multiple Agents for Mapping Fields. U.S. Patent No. 5,809,440.
- Biller, R.H. 1998. Reduced Input of Herbicides by Use of Optoelectronic Sensors. *Journal of Agricultural Engineering Resources*. 71:357-362.
- Blackshaw, R.E., L.J. Molnar, D.F. Chevalier and C.W. Lindwall. 1998. Factors Affecting the Operation of the Weed-Sensing Detectspray System. *Weed Science*. 46:127-131.
- Blackshaw, R.E., L.J. Molnar and C.W. Lindwall. 1998. Merits of a Weed-Sensing Sprayer to Control Weeds in Conservation Fallow and Cropping Systems. *Weed Science*. 46:120-126.
- Brown, R.B. and J.-P.G.A. Steckler. 1995. Prescription Maps for Spatially Variable Herbicide Applications in No-Till Corn. *Transactions of the ASAE*. 38(6):1659-1666.
- Brown, R.B., K. Bennett, H. Goudy and F. Tardif. 2000. Site Specific Weed Management With a Direct-Injection Precision Sprayer. ASAE Paper No. 001121. Annual International Meeting, Midwest Express Center, Milwaukee, Wisconsin, July 9-12.
- Doerge, T. 1999. Defining Management Zones For Precision Farming, http://www.pioneer.com/usa/technology/precision_farming_management_zones.htm. Accessed 20 Dec. 2000.
- Dupont, J.K., R. Campanella, M.R. Seal, J.L. Willers and K.B. Hood. 2000. Spatially Variable Insecticide Applications Through Remote Sensing. In *Proc. 2000 Beltwide Cotton Conference*, 426-428. San Antonio, TX, 4-8 Jan.
- Fulton, J.P., L.G. Wells, S.A. Shearer and R.I. Barnhisel. 1996. Spatial Variation of Soil Physical Properties: A Precursor to Precision Tillage. ASAE Paper No. 961002. International Meeting, Phoenix, Arizona. July 14-18.
- Hanks, J.E. and J.L. Beck. 1998. Sensor-Controlled Hooded Sprayer for Row Crops. *Weed Technology*. 12:308-314.
- Lowenberg-DeBoer, J. and A. Aghib. 1999. Average Returns and Risk Characteristics of Site-Specific P and K Management: Eastern Corn Belt On-Farm Trial Results. *Journal of Production Agriculture*. 12(2):276-282.
- Peterson, T. and N. Wollenhaupt. 1998. Considerations in Mapping Soil Properties or What About This Grid-Sampling?, <http://www.pioneer.com/usa/technology/i961004.htm>. Accessed 20 Dec. 2000.

- Petrzelka, P., S. Padgitt, K. Connelly. 1997. Teaching Old Dogs New Tricks: A Case Study in Promoting Integrated Crop Management. *Journal of Production Agriculture*. 10(4):596-602.
- Pierce, F.J. and D.D. Warncke. 2000. Soil and Crop Response to Variable-Rate Liming for Two Michigan Fields. *Soil Sci. Soc. Am. J.* 64:774-780.
- Reichenberger, L. 1998. Manure Where it Matters. *Successful Farming*. 96(2):34-35.
- Robertson, G.T. 2000. Precision Agriculture Technology for Horticulture Crop Production. *HortTechnology*. 10(3):448-451.
- Shearer, S.A., R.I. Barnhisel, J.L. Taraba, and S.F. Higgins. 1999. Swine and Dairy Waste Management Using Precision Agriculture. A Progress Report for Year I. Senate Bill 271 "An Act Relating to Agricultural Chemical Usage". February, 1999.
- Shonk, J.L., L.D. Gaultney, D.G. Schulze, and G.E. Van Scoyoc. 1991. Spectroscopic Sensing of Soil Organic Matter Content. *Transactions of the ASAE*. 34(5):1978-1984.
- Stone, M.L., J.B. Solie, W.R. Raun, R.W. Whitney, S.L. Taylor and J.D. Ringer. 1996. Use of Spectral Radiance for Correcting In-Season Fertilizer Nitrogen Deficiencies in Winter Wheat. *Transactions of the ASAE*. 39(5):1623-1631.
- Thornton, M. and D. Kelly. 16 Mar. 2000. Survey: Young Farmers See Exports as Key to Profits, <http://www.fb.org/news/nr/nr2000/nr0315.html>. Accessed 2 Feb. 2001.
- Thurman, M.E. and R.W. Heiniger. 1998. Using GPS to Scout Cotton for Variable Rate PIX (Mepiquat Chloride) Application. Proceedings of the 1998 Beltwide Cotton Conference. p. 1499-1502
- Tsunemori, T.S., C.N. Washmon, M.L. Stone, J.B. Solie and W.R. Raun. 2000. Optimum Field-of-View for Mapping Optically Sensed Data in Winter Wheat. ASAE Paper No. 001007. Annual International Meeting, Midwest Express Center, Milwaukee, Wisconsin, July 9-12.
- Veris Technologies. n.d. Frequently Asked Questions About Soil Electrical Conductivity, <http://www.veristech.com/faq.htm>. Accessed 20 Dec. 2000.
- Weedseeker. 7 Feb. 2001. Home page, <http://www.weedseeker.com>. Accessed 7 Feb. 2001.
- Wells L.G., S.A. Shearer, J.P. Fulton and L.W. Murdock. 2000. Assessment of Remote Sensing for Implementation of Precision Tillage. ASAE Paper No. 001084. Annual International Meeting, Midwest Express Center, Milwaukee, Wisconsin, July 9-12.
- Yule, I.J., G. Kohnen and M. Nowak. 1999. A Tractor Performance Monitor with DGPS Capability. *Computers and Electronics in Agriculture*. 23:155-174.

```

DECLARE SUB fileinfo (choice1%, choice2%, aboffset, noffset, numnoz%, separ, specvar)
DECLARE SUB info (choice1%, choice2%, aboffset!, noffset!, numnoz%, separ!, specvar)
DECLARE SUB infoprint (choice1%, choice2%, aboffset!, noffset!, numnoz%, separ!, specvar, ans$)
DECLARE SUB coord (xl(), yl(), nlat#(), nlon#(), lat2#, lon2#, numnoz%, pil)
DECLARE SUB offset (x(), y(), pi, tangle, oppangle, langle, rangle, numnoz%, choice1%, choice2%, aboffset, noffset,
separ, specvar)
DECLARE SUB angle (dir$, tangle!, oppangle!, langle!, rangle!, DeltaX#, DeltaY#, pil)
DECLARE SUB direction (NorS$, EorW$, dir$, DeltaX#, DeltaY#)

REM*****
REM*****convert.bas, convert.exe*****
REM*****Program to convert condensed site-specific sprayer*****
REM*****data into a text file for ArcView GIS*****
REM*****

REM*****Dimension all arrays*****
DIM z%(1 TO 50)
DIM x(1 TO 55)
DIM y(1 TO 55)
DIM dat(1 TO 55)
DIM nlat#(1 TO 55)
DIM nlon#(1 TO 55)

REM*****Initialize constants and variables*****
beginning% = 0
pi = 3.141593
flag% = 0
badgps = 0

REM*****Display program information*****
CLS
PRINT "convert.exe"
PRINT ""
PRINT "Converts sprayer data into a text file for ArcView GIS"
PRINT ""

REM*****Input the file name to be converted*****
INPUT "Enter the data file name. ", file$

REM*****Form the output file names*****
a% = LEN(file$)
b% = a% - 4
a$ = MID$(file$, 1, b%)
file1$ = a$ + ".inf"
file2$ = a$ + ".txt"
file3$ = a$ + ".smp"

OPEN file1$ FOR OUTPUT AS #2
OPEN file2$ FOR OUTPUT AS #3
OPEN file3$ FOR OUTPUT AS #4

PRINT #3, "Longitude,Latitude,Nozzle,%On"
PRINT #4, "Longitude,Latitude,Avg%On"

REM*****Set up the sprayer parameters*****
OPEN "c:\sssd\spara.txt" FOR APPEND AS #5
CLOSE #5

OPEN "c:\sssd\spara.txt" FOR INPUT AS #5
IF EOF(5) THEN
CLOSE #5
CALL info(choice1%, choice2%, aboffset, noffset, numnoz%, separ, specvar)
CALL fileinfo(choice1%, choice2%, aboffset, noffset, numnoz%, separ, specvar)
ELSE

```

Figure A. QBASIC programming for convert program CONV6.EXE.

```

INPUT #5, choice1%, choice2%, aboffset, noffset, numnoz%, separ, specvar
CLOSE #5
END IF

CALL infoprint(choice1%, choice2%, aboffset, noffset, numnoz%, separ, specvar, ans$)

IF ans$ = "y" THEN
    flag% = 1
ELSEIF ans$ = "Y" THEN
    flag% = 1
ELSE
    flag% = 0
END IF
DO WHILE flag% = 0
    CALL info(choice1%, choice2%, aboffset, noffset, numnoz%, separ, specvar)
    CALL fileinfo(choice1%, choice2%, aboffset, noffset, numnoz%, separ, specvar)
    CALL infoprint(choice1%, choice2%, aboffset, noffset, numnoz%, separ, specvar, ans$)
    IF ans$ = "y" THEN
        flag% = 1
    ELSEIF ans$ = "Y" THEN
        flag% = 1
    ELSE
        flag% = 0
    END IF
LOOP

REM*****Read in nol, time, date, and single GGA string*****
nol = 0
OPEN file$ FOR INPUT AS #1
DO WHILE NOT EOF(1)
    LINE INPUT #1, a$
    nol = nol + 1
LOOP
CLOSE #1
OPEN file$ FOR INPUT AS #1
LINE INPUT #1, mmddyy$
LINE INPUT #1, hhmmss$
LINE INPUT #1, GGA$

REM*****Write some of the info to the .inf file*****
output$ = "Original file name: " + file$
PRINT #2, output$
output$ = "Date recorded: " + mmddyy$
PRINT #2, output$
output$ = "Time recorded: " + hhmmss$
PRINT #2, output$
output$ = "Length of original file: " + LTRIM$(STR$(nol))
PRINT #2, output$

REM*****Break out hemisphere information*****
length% = LEN(GGA$)
p% = 1
FOR i% = 1 TO length%
    a$ = MID$(GGA$, i%, 1)
    IF a$ = "," THEN
        z%(p%) = i%
        p% = p% + 1
    END IF
NEXT i%
starter% = z%(3) + 1
cc% = z%(4) - z%(3) - 1
NorS$ = MID$(GGA$, starter%, cc%)
starter% = z%(5) + 1

```

Figure A. (Cont.)

```

cc% = z%(6) - z%(5) - 1
EorW$ = MID$(GGA$, starter%, cc%)
REM*****Shift in data*****
FOR I% = 1 TO nol - 5 'number of lines minus time, date, gga, and first
IF begining% = 0 THEN 'and last data lines
begining% = 1
LINE INPUT #1, line1$
LINE INPUT #1, line2$
LINE INPUT #1, line3$
ELSE
line1$ = line2$
line2$ = line3$
LINE INPUT #1, line3$
END IF
REM*****Count the number of data elements in the first line*****
length = LEN(line1$)
noe% = FIX((length - 35) / 3)

REM*****Break out UTC, GPSstat, Lat, Lon, and data*****
UTC$ = MID$(line2$, 2, 6)
GPSstat1% = VAL(MID$(line1$, 10, 1))
GPSstat2% = VAL(MID$(line2$, 10, 1))
GPSstat3% = VAL(MID$(line3$, 10, 1))
lat1# = VAL(MID$(line1$, 12, 11))
lat2# = VAL(MID$(line2$, 12, 11))
lat3# = VAL(MID$(line3$, 12, 11))
lon1# = VAL(MID$(line1$, 24, 11))
lon2# = VAL(MID$(line2$, 24, 11))
lon3# = VAL(MID$(line3$, 24, 11))
marker% = 36
FOR j% = 1 TO noe%
dat(j%) = VAL(MID$(line2$, marker% + (j% - 1) * 3, 2))
NEXT j%

REM*****Check gpsstatus and skip if not 2*****
IF GPSstat1% = 0 THEN
badgps = badgps + 1
GOTO 987
ELSEIF GPSstat2% = 0 THEN
badgps = badgps + 1
GOTO 987
ELSEIF GPSstat3% = 0 THEN
badgps = badgps + 1
GOTO 987
END IF

REM*****Convert gps data to decimal degrees (signed)*****
a$ = LTRIM$(STR$(lat1#))
b$ = MID$(a$, 1, 2)
c = VAL(b$)
d# = lat1# - c * 100
e# = d# / 60
lat1# = c + e#
a$ = LTRIM$(STR$(lon1#))
b$ = MID$(a$, 1, 2)
c = VAL(b$)
d# = lon1# - c * 100
e# = d# / 60
lon1# = c + e#
a$ = LTRIM$(STR$(lat2#))
b$ = MID$(a$, 1, 2)
c = VAL(b$)
d# = lat2# - c * 100
e# = d# / 60

```

Figure A. (Cont.)

```

lat2# = c + e#
a$ = LTRIM$(STR$(lon2#))
b$ = MID$(a$, 1, 2)
c = VAL(b$)
d# = lon2# - c * 100
e# = d# / 60
lon2# = c + e#
a$ = LTRIM$(STR$(lat3#))
b$ = MID$(a$, 1, 2)
c = VAL(b$)
d# = lat3# - c * 100
e# = d# / 60
lat3# = c + e#
a$ = LTRIM$(STR$(lon3#))
b$ = MID$(a$, 1, 2)
c = VAL(b$)
d# = lon3# - c * 100
e# = d# / 60
lon3# = c + e#
IF EorW$ = "W" THEN
a# = lon1# * -1
lon1# = a#
a# = lon2# * -1
lon2# = a#
a# = lon3# * -1
lon3# = a#
END IF
IF NorS$ = "S" THEN
a# = lat1# * -1
lat1# = a#
a# = lat2# * -1
lat2# = a#
a# = lat3# * -1
lat3# = a#
END IF

REM*****Break out first and last point coordinates*****
IF I% = 1 THEN
q$ = LTRIM$(STR$(lat1#))
r$ = MID$(q$, 1, 10)
firstpoint$ = r$
q$ = LTRIM$(STR$(lon1#))
r$ = MID$(q$, 1, 10)
firstpoint$ = firstpoint$ + "," + r$
firstutc$ = UTC$
ELSEIF I% = nol - 5 THEN
q$ = LTRIM$(STR$(lat3#))
r$ = MID$(q$, 1, 10)
lastpoint$ = r$
q$ = LTRIM$(STR$(lon3#))
r$ = MID$(q$, 1, 10)
lastpoint$ = lastpoint$ + "," + r$
END IF

REM*****Calculate DeltaX and DeltaY*****
DeltaX# = lon3# - lon1#
DeltaY# = lat3# - lat1#
REM*****Calculate Distance Traveled in feet*****
ftX# = DeltaX# * 365153.04# * COS((pi / 180) * lat2#)
ftY# = DeltaY# * 363184.56#
dist# = SQR(ftX# ^ 2 + ftY# ^ 2)
IF dist# < .05 THEN
GOTO 987

```

Figure A. (Cont.)

```

END IF
REM*****Determine direction of travel*****
CALL direction(NorS$, EorW$, dir$, DeltaX#, DeltaY#)

REM*****Calculate pertinent angles*****
CALL angle(dir$, tangle, oppangle, langle, range, DeltaX#, DeltaY#, pi)

REM*****Calculate nozzle offsets*****
CALL offset(x(), y(), pi, tangle, oppangle, langle, range, numnoz%, choice1%, choice2%, aboffset, noffset, separ,
specvar)

REM*****Calculate coordinates for each nozzle*****
CALL coord(x(), y(), nlat#(), nlon#(), lat2#, lon2#, numnoz%, pi)

REM*****Form up the output string and write it to the file*****
FOR j% = 1 TO numnoz%
lon$ = LTRIM$(STR$(nlon#(j%)))
lonb$ = MID$(lon$, 1, 11)
lat$ = LTRIM$(STR$(nlat#(j%)))
latb$ = MID$(lat$, 1, 11)
output$ = lonb$ + "," + latb$ + "," + LTRIM$(STR$(j%)) + "," + LTRIM$(STR$(dat(j%) + 1))
PRINT #3, output$
NEXT j%

REM*****Calculate an average for each point and write to file*****
asum = 0
FOR j% = 1 TO numnoz%
asum = asum + (dat(j%) + 1)
NEXT j%
avgdat = asum / numnoz%
output$ = LTRIM$(STR$(lon2#)) + "," + LTRIM$(STR$(lat2#)) + "," + LTRIM$(STR$(avgdat))
PRINT #4, output$

987
NEXT i%
CLOSE #1
a$ = "Second UTC in the file: " + firstutc$
PRINT #2, a$
a$ = "First point coordinates: " + firstpoint$
PRINT #2, a$
a$ = "Last point coordinates: " + lastpoint$
PRINT #2, a$
a$ = "Number of bad GPS data points: " + LTRIM$(STR$(badgps))
PRINT #2, a$
CLOSE #2
CLOSE #3
CLOSE #4
END

SUB angle (dir$, tangle, oppangle, langle, range, DeltaX#, DeltaY#, pi)
a# = ABS(DeltaX#)
b# = ABS(DeltaY#)
IF dir$ = "E" THEN
tangle = 0
oppangle = 180
langle = 90
range = 270
ELSEIF dir$ = "N" THEN
tangle = 90
oppangle = 270
langle = 180
range = 0
ELSEIF dir$ = "W" THEN

```

Figure A. (Cont.)

```

tangle = 180
oppangle = 0
langle = 270
rangle = 90
ELSEIF dir$ = "S" THEN
tangle = 270
oppangle = 90
langle = 0
rangle = 180
ELSEIF dir$ = "NE" THEN
theta = ATN(b# / a#)
tangle = (theta * 180) / pi
oppangle = tangle + 180
langle = tangle + 90
rangle = tangle + 270
ELSEIF dir$ = "NW" THEN
theta = ATN(b# / a#)
tangle = 180 - ((theta * 180) / pi)
oppangle = tangle + 180
langle = tangle + 90
rangle = tangle - 90
ELSEIF dir$ = "SW" THEN
theta = ATN(b# / a#)
tangle = 180 + ((theta * 180) / pi)
oppangle = tangle - 180
langle = tangle + 90
rangle = tangle - 90
ELSE
theta = ATN(b# / a#)
tangle = 360 - ((theta * 180) / pi)
oppangle = tangle - 180
langle = tangle - 270
rangle = tangle - 90
END IF
END SUB

SUB coord (x(), y(), nlat#(), nlon#(), lat2#, lon2#, numnoz%, pi)
FOR j% = 1 TO numnoz%
nlon#(j%) = lon2# + (x(j%) / (365153.04# * COS((lat2# * pi) / 180)))
nlat#(j%) = lat2# + (y(j%) / 363184.56#)
NEXT j%
END SUB

SUB direction (NorS$, EorW$, dir$, DeltaX#, DeltaY#)
IF DeltaX# > 0 THEN
IF DeltaY# > 0 THEN
dir$ = "NE"
ELSEIF DeltaY# < 0 THEN
dir$ = "SE"
ELSE
dir$ = "E"
END IF
ELSEIF DeltaX# < 0 THEN
IF DeltaY# > 0 THEN
dir$ = "NW"
ELSEIF DeltaY# < 0 THEN
dir$ = "SW"
ELSE
dir$ = "W"
END IF
ELSE
IF DeltaY# > 0 THEN
dir$ = "N"

```

Figure A. (Cont.)

```

ELSE
  dir$ = "S"
END IF
END IF
END SUB
SUB fileinfo (choice1%, choice2%, aboffset, noffset, numnoz%, separ, specvar)
OPEN "c:\sssd\lpara.txt" FOR OUTPUT AS #5
PRINT #5, choice1%, choice2%, aboffset, noffset, numnoz%, separ, specvar
CLOSE #5
END SUB

SUB info (choice1%, choice2%, aboffset, noffset, numnoz%, separ, specvar)
CLS
PRINT "Some information about your sprayer is required"
PRINT ""
PRINT "Is the left-most nozzle:"
PRINT "1. Left of the antenna"
PRINT "2. In line with the antenna"
PRINT "3. Right of the antenna"
PRINT ""
INPUT "Enter your choice (1-3) ", choice1%
PRINT ""
PRINT ""
PRINT "Is the boom:"
PRINT "1. In front of the antenna"
PRINT "2. In line with the antenna"
PRINT "3. Behind the antenna"
PRINT ""
INPUT "Enter your choice (1-3) ", choice2%
PRINT ""
IF choice2% <> 2 THEN
  INPUT "Enter the distance between the antenna and the boom in inches. ", aboffset
ELSE
  aboffset = 0
END IF
PRINT ""
IF choice1% <> 2 THEN
  PRINT "Enter the distance between the antenna center-"
  INPUT "line and the left-most nozzle in inches. ", noffset
ELSE
  noffset = 0
END IF
PRINT ""
INPUT "Enter the number of nozzles. ", numnoz%
PRINT ""
INPUT "Enter the distance between nozzles in inches. ", separ
PRINT ""
INPUT "Are you using a special nozzle configuration? (Y or N) ", spec$
IF (spec$ = "Y") OR (spec$ = "y") THEN
  specvar = 1
ELSE
  specvar = 0
END IF
END SUB
SUB infoprint (choice1%, choice2%, aboffset, noffset, numnoz%, separ, specvar, ans$)
CLS
IF choice1% = 1 THEN
  PRINT "The left-most nozzle is left of the antenna"
ELSEIF choice1% = 2 THEN
  PRINT "The left-most nozzle is in line with the antenna"
ELSEIF choice1% = 3 THEN
  PRINT "The left-most nozzle if right of the antenna"
ELSE
  PRINT "DATA IS NOT VALID"

```

Figure A. (Cont.)

```

END IF
IF choice2% = 1 THEN
  PRINT "The boom is in front of the antenna"
ELSEIF choice2% = 2 THEN
  PRINT "The boom is in line with the antenna"
ELSEIF choice2% = 3 THEN
  PRINT "The boom is behind the antenna"
ELSE
  PRINT "DATA IS NOT VALID"
END IF
a$ = LTRIM$(STR$(aboffset))
b$ = "The distance between the antenna and the boom is " + a$ + " inches."
PRINT b$
a$ = LTRIM$(STR$(noffset))
b$ = "The distance from the antenna center-line to the"
c$ = "left-most nozzle is " + a$ + " inches."
PRINT b$
PRINT c$
a$ = LTRIM$(STR$(numnoz%))
b$ = "There are " + a$ + " nozzles."
PRINT b$
a$ = LTRIM$(STR$(separ))
b$ = "Nozzle spacing is " + a$ + " inches."
PRINT b$
IF specvar = 1 THEN
  PRINT "A special nozzle configuration is being used."
ELSE
  PRINT "No special nozzle configuration is being used."
END IF
PRINT ""
INPUT "Is the information correct? (Y or N) ", ans$
END SUB
SUB offset (x(), y(), pi, tangle, oppangle, langle, range, numnoz%, choice1%, choice2%, aboffset, noffset, separ,
specvar)
DIM q(24)
IF choice2% = 1 THEN
  r = aboffset / 12
  xcoor1 = r * COS((tangle * pi) / 180)
  ycoor1 = r * SIN((tangle * pi) / 180)
ELSEIF choice2% = 3 THEN
  r = aboffset / 12
  xcoor1 = r * COS((oppangle * pi) / 180)
  ycoor1 = r * SIN((oppangle * pi) / 180)
ELSE
  xcoor1 = 0
  ycoor1 = 0
END IF
IF choice1% = 1 THEN
  r = noffset / 12
  xcoor2 = xcoor1 + (r * COS((langle * pi) / 180))
  ycoor2 = ycoor1 + (r * SIN((langle * pi) / 180))
ELSEIF choice1% = 3 THEN
  r = noffset / 12
  xcoor2 = xcoor1 + (r * COS((range * pi) / 180))
  ycoor2 = ycoor1 + (r * SIN((range * pi) / 180))
ELSE
  xcoor2 = xcoor1
  ycoor2 = ycoor1
END IF
IF specvar = 1 THEN
  OPEN "c:\sssd\conf.txt" FOR INPUT AS #5
  i = 1
  DO WHILE NOT EOF(5)
    INPUT #5, q(i)

```

Figure A. (Cont.)

```

i = i + 1
LOOP
CLOSE #5
rsum = 0
FOR i = 1 TO numnoz%
r = (q(i - 1) / 12)
rsum = rsum + r
x(i) = xcoor2 + (rsum * COS((range * pi) / 180))
y(i) = ycoor2 + (rsum * SIN((range * pi) / 180))
NEXT i
ELSE
FOR i = 1 TO numnoz%
r = (i - 1) * (separ / 12)
x(i) = xcoor2 + (r * COS((range * pi) / 180))
y(i) = ycoor2 + (r * SIN((range * pi) / 180))
NEXT i
END IF
END SUB

```

Figure A. (Cont.)

Vita

Nathan Dwayne Sewell was born in Somerset, Kentucky on April 21, 1977. He grew up on a small dairy farm, and attended school in the Pulaski County school system. Nathan graduated from High School in 1995 where he received the advanced Comprehensive Diploma.

The following August he began his academic career at Somerset Community College (SCC). After obtaining several course credits at SCC, he transferred to Eastern Kentucky University where he pursued a degree in Agriculture with an emphasis in Mechanization. While at ECU, Nathan was involved in several activities including the agriculture honor society Delta Tau Alpha. Nathan obtained a Bachelor of Science in Agriculture with a Business Minor from ECU in December 1999.

In January 2000, Nathan began graduate school at the University of Tennessee at Knoxville, in the Department of Agricultural and Biosystems Engineering. There he majored in Biosystems Engineering Technology with an emphasis in power and machinery while working with precision agriculture, and was awarded membership in Gamma Sigma Delta, honor society of agriculture. Nathan graduated from UT in May 2002, with a Master of Science in Biosystems Engineering Technology.

3784 2850 28
88-87-82 HFB 