SITE-SPECIFIC STRATEGIES FOR COTTON MANAGEMENT

A Thesis

by

MARCELO DE CASTRO CHAVES STABILE

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2005

Major Subject: Agronomy

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May 2005

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ABSTRACT

Site-Specific Strategies for Cotton Management. (May 2005)

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The use of site-specific data can enhance management decisions in the field. Three different uses of site-specific data were evaluated and their outcomes are promising. Historical yield data from yield monitors and height data from the HMAP (plant height mapping) system were used to select representative areas within the field, and areas of average conditions were used as sampling sites for COTMAN, a cotton management expert system. This proved to be effective, with predicted cutout dates and date of peak nodal development similar to the standard COTMAN approach. The HMAP system was combined with historical height data for variable rate application of mepiquat chloride, based on the plant growth rate. The system performance was evaluated, but weather conditions in 2004 did not allow a true evaluation of varying mepiquat chloride. A series of multi-spectral images were normalized utilizing the soil line transformation (SLT) technique and normalized difference vegetation index (NDVI) was calculated from the transformed images, from the raw image and for the true reflectance images. The SLT technique was effective in tracking the change in true reflectance NDVI in some images, but not all. Changes to the soil line extraction program are suggested so that it more effectively determines soil lines.

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I would like to thank my friends from College Station, and Brazil for the never-ending support and finally, I would like to dedicate this Thesis to my father, Carlos Stabile Neto. Even though he is physically absent, his figure continues to inspire me.

TABLE OF CONTENTS

Page

ABSTRACT iii

ACKNOWLEDGMENTS iv

TABLE OF CONTENTS v

LIST OF FIGURES vii

LIST OF TABLES ix

CHAPTER

I INTRODUCTION 1

II USE OF SITE-SPECIFIC DATA FOR COTMAN SITE SELECTION 6

- Introduction 6
- Literature Review 8
- Material and Methods 11
- Results and Discussion 16
  - Dryland 17
  - Irrigated 24
- Summary 37
- Conclusions 39
- Future Research 39

III REAL TIME VARIABLE RATE APPLICATION OF MEPIQUAT CHLORIDE 40

- Introduction 40
- Literature Review 43
- Material and Methods 48
- Results and Discussion 53
- Conclusions 61
- Future Research 62

IV VALIDATION OF THE SOIL LINE TRANSFORMATION TECHNIQUE 64

- Introduction 64

CHAPTER Page

- Literature Review 66
- Material and Methods 70
  - Image Preprocessing 70
  - Testing the Soil Line Transformation Technique 74
- Results 77
  - Whole 77
  - Sub-Image 82
- Summary 90
- Conclusions 92
- Future Research 92

V SUMMARY AND CONCLUSIONS 94

REFERENCES 95

APPENDIX A 99

APPENDIX B 101

VITA 103

LIST OF FIGURES

FIGURE Page

1. Selected COTMAN sampling points..14

2. 2004 Average temperatures relative to historical data (USDA & NOAA, 2004)...17

3. Description of COTMAN sampling sites...18

4. COTMAN curves generated for each sampling strategy and combined................19

5. COTMAN curves generated for the dryland cotton from mean yield sampling.....20

6. COTMAN curves generated for the dryland cotton from mode yield sampling 21

7. Location and labeling of COTMAN sampling sites in the irrigated field..............25

8. COTMAN curves generated for each sampling strategy and combined................26

9. COTMAN curves generated from combination of expert sites and all data...........27

10. COTMAN curves generated from combination of height sites and all data...........28

11. COTMAN curves generated from combination of yield sites and all data............29

12. Histogram of height distribution on 6/20/03 30

13. Histogram of yield distribution from 2003 30

14. COTMAN curves for the NE and NW cluster of sampling sites 34

15. Sketch of the HMAP RoG system...51

16. Plant height profile on different dates 55

17. Plant height profile on different dates with some bad data 56

18. Profile of average internode length and desired mepiquat chloride application rates on July 22nd..57

19. Calculated and applied mepiquat chloride rates..58

20. Height profiles of machine based and manual data collected on the same area 60

FIGURE Page

21. Distribution of reflectance values in an image in the red and NIR regions of the electromagnetic spectrum 68

22. Selected region of interest from whole image 75

23. Area used for the sub-image dataset 76

24. Calculated soil line from the WHOLE dataset on 7/13/1999 78

25. Histogram of NDVI distribution on 6/23/1999 from the WHOLE dataset 80

26. Temporal trends of the NDVI's for all different methods 81

27. Calculated and manual soil lines from the sub-image dataset on 7/13/1999 83

28. Histogram of NDVI distribution on 6/23/1999 from the sub-image dataset 85

29. Histogram of NDVI distribution on 7/20/1999 from the sub-image dataset 86

30. Histogram of NDVI distribution on 8/10/1999 from the sub-image dataset 87

31. Temporal trends of the NDVI's for all different methods 88

LIST OF TABLES

TABLE Page

1. Cochran's COTMAN sampling scheme 10
2. Daily F-test values for dryland area from the ANOVA 22
3. Daily F-test values for the contrasts comparing combination of dryland sites 23
4. Predicted cutout dates for the dryland field...23
5. Daily F-test values for irrigated area from the ANOVA..31
6. Daily F-test values for the contrasts comparing combination of irrigated sites......32
7. Predicted cutout dates for the irrigated field 33
8. Predicted cutout day by method and cluster..35
9. Predicted cutout and peak nodal development for combination of sites.................36
10. Experimental plot 49
11. Description of the hardware used...52
12. ANOVA on yield for the variable rate mepiquat chloride experiment 54
13. Correlation coefficients from machine based and manual measurements 59
14. ANOVA table for average height within date..60
15. Tukey grouping for average height within date (alpha =0.01)...............................61
16. Imaging dates 71
17. Geo-referencing statistics...72
18. Soil line parameters from the WHOLE dataset..77
19. Correction parameters for the WHOLE dataset 79
20. Regression parameters from the soil line program...82

TABLE Page

21. Regression parameters from the manually extracted soil lines 83

22. Correction parameters for the sub-image dataset 84

CHAPTER I

INTRODUCTION

Globalization and advances in competitiveness of agriculture have made the farming business much tougher for agriculturalists. Increasing input costs and decreasing world market prices have caused many farmers to be on the edge of profitability. To solve this problem, farmers must use any tools they can to maximize returns and optimize production. Cotton is one of the high-risk crops, where the costs are elevated and profit varies.

A tool that has been available to farmers, and that aids in decision-making is precision agriculture (PA). This tool allows farmers to better understand their land, therefore, aiding in more rational management decisions. Precision agriculture is made possible by technological advances, but it relies upon many years of work to make scientifically justified and economic decisions within the field.

Through the use of precision agriculture we expect to aid in optimizing cotton production, while decreasing costs. The use of PA will enhance the value of site-specific data collected manually, mechanically or remotely. The use of site-specific data will allow more sound decisions, which will enable the producer to improve localized management.

This thesis follows the style and format of *Applied Engineering in Agriculture.*

COTMAN is a cotton management system that aids producers in determining plant stress, monitoring development, application of seasonal insecticides and end of season harvest aids. Decisions to apply water or chemicals to the crop are based on farmer's experience and knowledge. COTMAN can aid those decisions by providing a better understanding of crop condition. COTMAN is based upon detailed observations of cotton development at selected points in the field and knowledge of cotton physiology to suggest management actions. COTMAN literature suggests that selected sites for data collection represent the field average conditions. While the suggested number of sites is four for a ten-acre field, farmers typically use fewer sites, often only one or two, due to the time and costs of data collection. This makes it especially necessary that the selected sites be as representative of the field average conditions as possible. Use of detailed data, such as plant height, remotely sensed images or yield maps from previous years, has the possibility to assist in better site selection. Through the use of this data, one potentially can optimize site selection, once areas of consistent average yield and average height are identified.

Growth regulators such as mepiquat chloride are applied during the crop cycle to minimize vegetative plant growth and to aid in harvest, by maintaining the plants at a tolerable height. The application rate is commonly a single rate for the entire field, selected by the consultant, extension agent, or farmer, based on "average" plant status. One of the methods for determining the mepiquat chloride application rate is measuring the average internode length of the top five nodes of the plant, by using the mepiquat chloride rate and timing (MEPRT) stick. If the average internode length is greater than

3.6 cm, then the plant will receive an application of mepiquat chloride. Studies indicate that the concentration of 12 mg of mepiquat chloride per kg of plant biomass is the optimum application rate to reduce vegetative growth. A mepiquat chloride rate and timing (MEPRT) program has been used to calculate the appropriate rate to achieve the optimum concentration, based on the number of nodes, average internode length and plant population.

Applying mepiquat chloride at a variable rate will not only maximize its efficiency, but also standardize plant height for optimum harvest. Some variable rate application strategies have been based on plant height, where taller plants receive more mepiquat chloride and shorter plants less. The problem is that the growth regulator can only affect those nodes that are still growing (the upper few). Tall plants that have stopped growing will receive an unnecessary high rate. An alternative to a variable rate application according to height is using the height mapping system (HMAP) to calculate plant rate of growth. Through the use of historical height, the HMAP system can determine the recent rate of growth (cm/day) and, using the previous mepiquat chloride applications at each point throughout the field, the system will determine the appropriate application rate to achieve the desired concentration of mepiquat chloride. The HMAP system will determine the plant height and application rate in real time.

The use of vegetation indices for assessing crop status has been sold by remote sensing firms and used by consultants and farmers to assess the crop status during the growing season. Images, which are used for extraction of the vegetation indices, are usually composed by the combination of bands. The bands correspond to different parts of the spectra and the most commonly used ones are: blue, green, red and near infrared. One of the most used indices is the normalized difference vegetation index (NDVI). It is a relative index with values from -1 to 1, where the near infrared (NIR) and red reflectance bands are considered. The formula for this index is as follows:

$$\mathrm{NVDI} = \frac{(\mathrm{NIR} - \mathrm{red})}{(\mathrm{NIR} + \mathrm{red})} \tag{1}$$

This index is correlated with leaf area index, and therefore an indicator of plant biomass, which can be used by farmers to assess crop stress and to track plant development. Unexpected changes in NDVI can be indicative of plant stress such as water or nutrient deficiency that can be seen much earlier through imagery than in the field. Since multiple images are acquired during the season, the user often wants to compare images from different dates to track plant development. Images taken on different dates are radiometrically different, since the imaging conditions imposed by the atmosphere, sun angle and time of day and year, are variable. There are various methods of image calibration, which can be absolute or relative. Calibration techniques include using invariant features naturally occurring in the image, placing reflectance tarps in the field, or acquiring radiance data at the time of imaging. While absolute image calibration is the optimal technique, when imaging large areas (common for agricultural remote sensing), it is often not possible to have this type of calibration information. Another approach would be to do a relative calibration to features that would be constant and present in crop images. The soil line transformation (SLT) technique takes advantage of the well-known soil line concept, which describes a regression line that is inherent to each soil, and therefore present throughout the year. The SLT uses one of the images as the reference (to which all others will be calibrated), and determines the soil lines for the set of images. The transformation program then does a second regression to match the red and near infrared values of each of the images to the reference. The SLT has been proven to be effective in normalizing some images, but not all. The SLT, though has not yet been compared to indices extracted from true reflectance images.

Using the tools provided by precision agriculture for data collection and interpretation allows a more viable way to make more sound decisions that will ultimately benefit producers. Applying mepiquat chloride in a real time variable rate, will not only make plant height more uniform, but may also optimize harvest. Use of site-specific data for COTMAN site selection will aid producers in extracting the best information, while minimizing sampling time and costs. Using SLT normalization to improve the information content of a series of remotely sensed images will give farmers the opportunity to understand better the evolution of their crops and aid in decision-making. Therefore, precision agriculture is a tool that can help increase profitability and make cotton production better.

The hypothesis of this research is that by using site-specific data, one can increase the quality of the information from the field and improve management decisions. The objectives, which will be treated individually as chapters, are to:

- *Optimize COTMAN site selection* through use of historical data;
- *Evaluate variable rate applications of mepiquat chloride, test the rate of growth (RoG) algorithm* for mepiquat chloride application rate; and
- *Evaluate the soil line technique* for calibration of multi temporal images.

CHAPTER II

USE OF SITE-SPECIFIC DATA FOR COTMAN SITE SELECTION

INTRODUCTION

Cotton is known to be a management-intensive crop. Due to its indeterminate growth habit and a complex structure, it is important to monitor crop development to make sound management decisions. A software package developed by the University of Arkansas called COTMAN was developed for such purpose. Since it is a crop monitoring software, it relies on weather and field data. While the benefits of using COTMAN are higher than its costs, labor is still a major factor in adopting its use.

COTMAN literature suggests the use of four sampling sites for a 16 ha (40 ac) field and an additional site for every 4 ha (10 ac), up to a 32 ha (80 ac) field. In each one of the sampling sites, 10 plants should be used for data collection.

Selection of COTMAN sampling sites within the field is usually done either by the farmer or consultant. These points should be representative of the area that will be managed with the information. Use of site-specific data, collected during the current or previous growing seasons, can potentially aid producers in better site selection, therefore improving the accuracy of the information.

Fields tend to have spatial variability according to elevation, soil types, and many other factors that directly affect crop development. Since COTMAN site selection is done early in the season, it is sometimes difficult to determine areas representative of the field. By using historical data, such as yield maps, farmers have the opportunity to investigate yield differences across the field and therefore determine areas of average yield. By knowing these areas, they can make better decisions in site selection. A question regarding the use of historical yield maps is whether to use the mean yield (which can be strongly affected by extreme values) or the most frequent value (mode) of yield for site selection. Plant height maps, collected by the HMAP system, have also been used for determining representative areas within a field, and sites selected from this data.

Yield and height data, are very useful, as they characterize the field with very intensive sampling, and therefore capture its variability. Remotely sensed images also have a potential for use of site selection, once they are snapshots of the field at a certain point of crop development.

The hypothesis of this study was that the use of site-specific data would aid in the selection of more representative sites within a field, therefore potentially reducing the number of sampling sites required compared to current COTMAN recommendations.

The objectives were to:

- Determine if a reduced number of sampling sites selected using site-specific data will characterize average field conditions as well as COTMAN recommended procedures; and
- Evaluate height and yield as data sources for selecting representative sampling sites within the field.

LITERATURE REVIEW

COTMAN is a software package developed by the University of Arkansas that utilizes plant monitoring and weather data together with farm and field parameters to assist in management decisions from squaring to defoliation (Cochran et al., 1996). The software consists of two components: SQUAREMAN and BOLLMAN (UAAES, 1998). COTMAN is an excellent record keeping and crop characterization software that will provide useful information to producers and consultants (Teague et al., 2000).

COTMAN data collection starts by measuring stand density (only done once per season). This is important, as plant density will affect growth patterns (UAAES, 1998). Once plant density has been measured, SQUAREMAN data collection can be initiated. It provides the necessary information to compute square shed rates, measurements of plant vigor and a comparison of nodal development to the target curve from first square to first flower. Numbers of squares are counted on the first fruiting position of each sympodia from the top of the plant, down to the last square. Along with square counts, on the first time SQUAREMAN data is collected, node of first sympodium is also counted (only once per season) to determine total nodal development and calculate height-to-node ratio. Another measure that is collected during square counts is plant height, and this is done every time squares are counted. Once flowering begins, SQUAREMAN is terminated and BOLLMAN data collection is initiated. This is done by counting the number of nodes above white flower (NAWF), to monitor field development and to determine date of physiological cutout. NAWF is measured by counting the number of nodes above the top-most white flower in each plant. NAWF counts should be terminated when it is equal or less than five. Four to eight sampling sites per field have been suggested, with at least four sites for any field, and an additional sampling site for every four hectares (10 ac.) (UAAES, 1998). Ten plants should be measured at each one of the sampling sites, as described by the COTMAN user guide (UAAES, 1998). This number of plants per site is based on previous studies that tried to optimize sample size for determining insect infestation (Vodrazka, 1998).

COTMAN uses in-season crop monitoring to assist in identifying cutout dates for individual fields, provides end of season management decision aids for insecticide termination timing, ranks fields by maturity, and assists in determining defoliation and harvest time (UAAES, 1998). Using COTMAN can result in more efficient application of inputs and earlier harvesting dates. COTMAN literature (UAAES, 1998) suggests the use of heat units counted after cutout as a parameter for determination of when to apply defoliants and to stop late season application of insecticides. UAAES (1998) showed that, for Arkansas conditions, there was no detrimental effect in yield when control for weevil and bollworm was terminated 350 heat units after cutout. Defoliation is to be done at 850 heat units after cutout.

The management information obtained from COTMAN is only as good as the data input by the user, and it is very important that the sampling and data collection sites are representative of the field (Vodrazka, 1998).

Robertson et al. (1997) reported that the time used for COTMAN data collection varied from 20 to 23 minutes per field visit, although this does not account for management time required for interpretation and development of recommendations. In another study, Stewart et al. (2000) calculated an average time expenditure of 31.6 minutes per site. The direct cost of data collection ranged from US$3.14/ha to US$4.32/ha (US$1.27 to US$1.75/ac) for a once a week data collection, and about US$8.62/ha (US$3.49/ac) for twice a week data collection. According to UAAES (1998), COTMAN generated savings of US$19.20/ha (US$7.77/acre) in northeastern Arkansas, US$33.46/ha (US$13.54/ac) in eastern/central Arkansas and savings of US$52.39/ha (US$ 21.20/ac) in southeastern Arkansas.

Cochran et al. (1999) suggests a sampling scheme that minimizes the variance of data and also indicates that increasing number of sampling sites is not as effective as increasing number of plants per site (table 1). Characterization of the field can be done effectively with fewer sites than suggested, according to Cochran et al. (1999). An adequate selection of these sites is necessary, so that they represent field conditions (Vodrazka, 1998).

Table 1. Cochran's COTMAN sampling scheme

	COTMAN	Minimum variance ranges
Plant Height	4-8 sites 2 measures per site	5-11 sites 2-4 measures per site
Squaring Nodes	4-8 sites 10 plants per site	3-10 sites 7-14 plants per site
Square Relation	4-8 sites 10 plants per site	2-7 sites 11-27 plants
NAWF	4-8 sites 10 plants per site	3-8 sites 7-23 plants per site

To assess in-field variability, Geiger (2004) selected COTMAN sampling sites from areas that were within 1/8 standard deviation of the average plant height. By using this methodology, he found that the selected sites were representative of the field, but he did not use the selected sites for COTMAN sampling. Height was collected using the Texas A&M spatial plant height mapping system (HMAP) (Beck, 2001). The system uses a mini-array with light beams that are scanned at 200 Hz, and generates a histogram of blocked beams, which are used to calculate plant height. Since the system is mounted directly in front of the sprayer, data can be collected at any time in the season when the sprayer is operated in the field. Geiger (2004) used three height maps from 2003 to identify areas of average plant height.

Previous work done by Vodrazka (1998) and Cochran et al. (1999), indicate that field characterization can be done with fewer sites than recommended by COTMAN, while minimizing the variance of the data. It is necessary though that the sites selected for sampling are as representative of the field as possible. Previous work done by Geiger (2004) indicates that site-specific data such as yield and height maps can be used for selection of representative areas within the field.

MATERIAL AND METHODS

To test the effectiveness of different data sources (yield and height) as an input for selecting representative sites within the fields, an experiment was set up. Different sampling strategies were considered and COTMAN recommendations were followed throughout the season.

The experimental area was located at the Texas A&M University IMPACT Center (UTM zone 14N, 746613 E and 3379857 N) in Burleson County (Brazos River Valley of south-central Texas). Two different fields were used for the experiment: a continuous cotton, irrigated, 7.5 ha field (I-2) with 0.762 m (30 in.) row spacing, planted with DPL-444 on April 5th; and a grain-cotton rotated, dryland, 5 ha field (D-8) with 1.016 m (40 in.) row spacing, planted with ST-5599 on April 1st. The irrigated field consists of a Norwood silty clay loam, as does most of the dryland field. A portion of the dryland field, on the eastern edge, is a Norwood silty loam. Selected site coordinates were located using a differential global positioning system (DGPS) and the sites were marked with flags to maintain sampling consistency.

Site selection was done through these methods:

1. Historical mean yield – Sampling points were identified where the yield was within 1/8 standard deviation of the mean. Points closer to the edge of the field were more suitable, since this minimized sampling time. In the irrigated and dryland field there were three sites selected using this method.

2. Historical mode yield – These points were chosen the same way as in method 1, but used the mode instead of the mean. There were three sites selected in the dryland field using this method.

3. Historical average height – Five height maps from the years for 2002 and 2003 were used. Suitable points were within 1/8 of the standard deviation of the mean for at least three out of five height maps as in the described method by Geiger (2004). Three sites were selected using this strategy in the irrigated field.

Directed Sampling – ECe sampling, assessment, and prediction – response surface sampling design software (ESAP-RSSD) (USDA-ARS., 1999) was developed to optimize the selection of soil sampling points from soil conductivity data. ESAP-RSSD was developed to select sites, which would in theory optimize the estimation of the prediction model, by using the response surface design. It was developed to work with electric conductivity data but can be used with other types of data that contain spatial information as well. In this study, ESAP-RSSD was used with both yield and height data. No sampling was done at the points suggested by ESAP-RSSD because they tended to identify areas of extreme values in the field rather than typical sites. Points selected were usually on field borders and not representative of average field conditions. For COTMAN sampling, the goal was characterizing field average conditions, not the range of variability.

Sites were selected using these concepts, and a total of 16 points were selected, exceeding the COTMAN recommendation. In the dryland area, three sites were selected using mean yield, and three from mode yield. The sites were selected based on grain yield from 2001 when the field was cultivated with sorghum. Another factor that was considered for the selection of sampling sites was the use of mean values of NDVI. Two aerial images from 2003, when the field was cultivated with sorghum, taken on 7/23/2003, were used for calculation of NDVI. Based on areas of average NDVI values from the images, data was used to confirm the mean and mode yield selected points for final site selection.

There were initially ten sites selected in the irrigated cotton area. Three of the sites were selected using mean yield from three years of yield maps. The next three were selected from the points that were consistently of average height from at least three out of five height maps from 2002 and 2003.The last four were points selected by the COTMAN expert in 2003. One of these expert points was not considered in the analysis, since due to poor cotton stand and weed infestation it was shredded during the season. Due to unusually high rainfall, I-2 was irrigated only once, on 7/24/2004. Figure 1 illustrates the experimental areas.

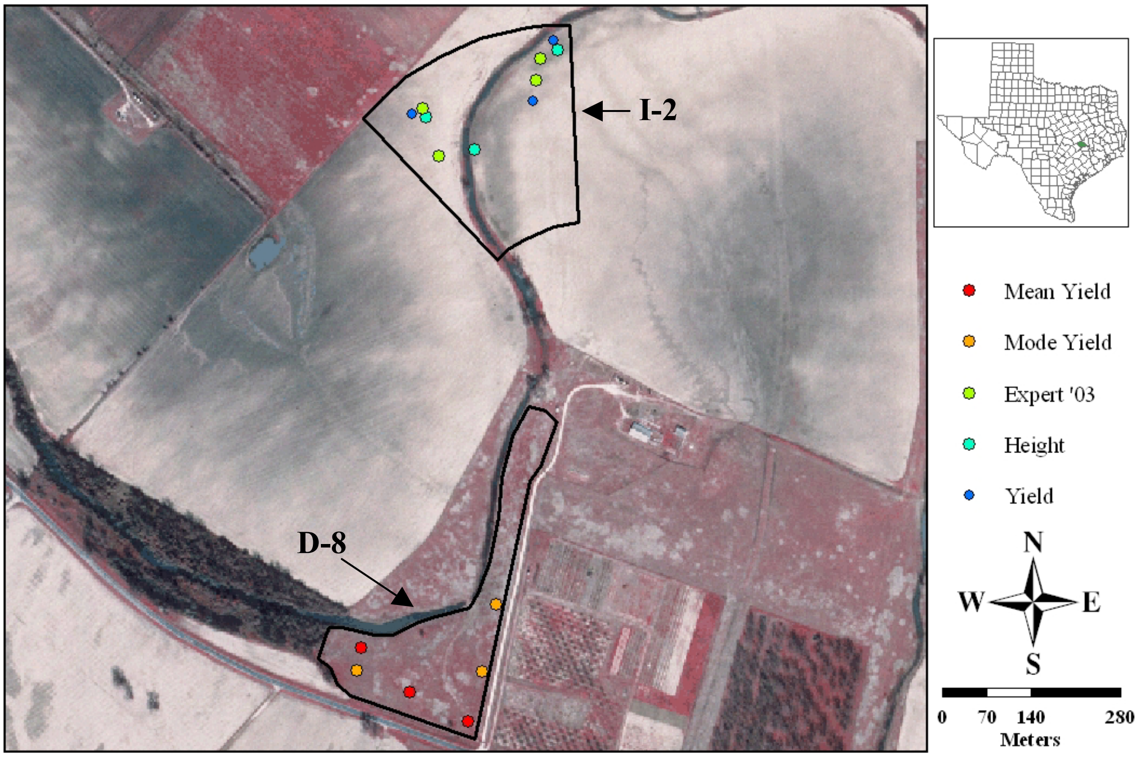


Figure 1. Selected COTMAN sampling points

COTMAN sampling was conducted, and SQUAREMAN data points were collected twice in the irrigated area (6/15 and 6/21) and three times in the dryland area (6/9, 6/15 and 6/21). BOLLMAN data was collected on four dates for both the dryland and irrigated areas (7/5, 7/13, 7/23 and 7/28) and on a fifth date for the irrigated cotton (8/3).

Data collection was done according to COTMAN recommendations, in which 10 plants were sampled at each site. Farm and field information was input to the software. Stand counts were done for both experimental areas on 5/21. First fruiting node was counted on 6/09 for the dryland area and 6/15 for the irrigated cotton. Squares were counted from the top of the plant down from the first fully expanded leaf. The presence or absence of squares on the first fruiting position was recorded and plant height measurements were averaged over the sampling site. Once plants started flowering, nodes above white flower (NAWF) were counted instead of squares. This was done by counting the number of nodes above the last white flower on the plant. Data collection was terminated once NAWF < 5 for two consecutive weeks. Data was input into the COTMAN software and reports were generated. Both available versions of COTMAN, V2 and V3, were used for comparison, and COTMAN V3 was selected for further analysis of the data.

Development curves were generated in COTMAN for each field. For the dryland area, curves were generated for the three sampling sites from each strategy (mean and mode yield) and another curve was generated with the combined six sites. For the irrigated cotton, curves were generated for selected points from: height, mean yield and the expert selected points. A combined curve for all nine points was also generated and used for comparison. Since each sampling strategy consisted of three sites, curves were also generated using only two of the sites, to check if the same trend was characterized just by using two instead of three or by using the combined sites.

Within the irrigated area, there were sites selected from different sampling schemes that were clustered together in the northeast and northwest portions of the field. The clusters of points were used to investigate the variance between the site selection methods. Since points were clustered together, it is assumed that there should be minimal differences within them, and therefore one could compare the methods of site selection. Date of peak nodal development and suggested cutout day were used to compare these individual points within the methods.

An analysis of variance was conducted individually by date, to assess source of variability. The different sampling selection methods were considered as the treatments, while the sites were the replications. To assess variability within the methods, orthogonal contrasts were estimated by comparing every pair of sites of each method to the combined data that included all sampling sites within the field. Each method consisting of three sampling sites was also compared to the combined data.

RESULTS AND DISCUSSION

The year of 2004 was not typical. Even though planting was done in early April, cool rainy weather delayed plant development. The temperature drop that occurred around ten days after planting affected crop development, and delayed the whole crop cycle (figure 2).

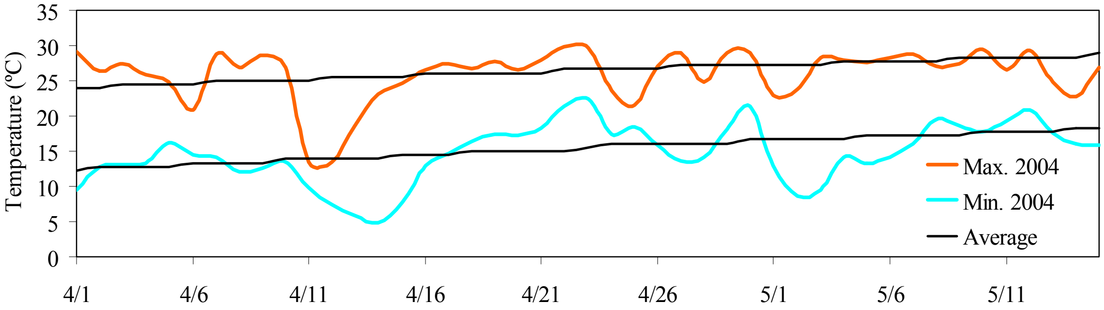


Figure 2. 2004 Average temperatures relative to historical data (USDA & NOAA, 2004)

Rainfall was also a factor that retarded plant development. The delay in cotton development shown in every curve hereafter is primarily attributed to the weather. Planting was done in the normal period and the only factor that can explain the delayed crop development are the very low temperatures 10-20 days after planting associated with a high amount of rainfall. In April, May and June the rainfall was 21, 77 and 204 mm above average respectively.

DRYLAND

The dryland field is somewhat uniform, and variability in plant height and crop development was small except for two small portions of the field. In one of these areas, there was an accumulation of water in a small portion of the center of the field, where cotton was shorter and crop development delayed. The other portion is on the southeastern edge of the field, where mepiquat chloride was not applied, due to an electricity line preventing the airplane from flying there. In this area, cotton was very tall and had a very low yield. Rainfall was abundant and water was not a major stress factor. An illustration of the labeled sampling sites is shown in figure 3.

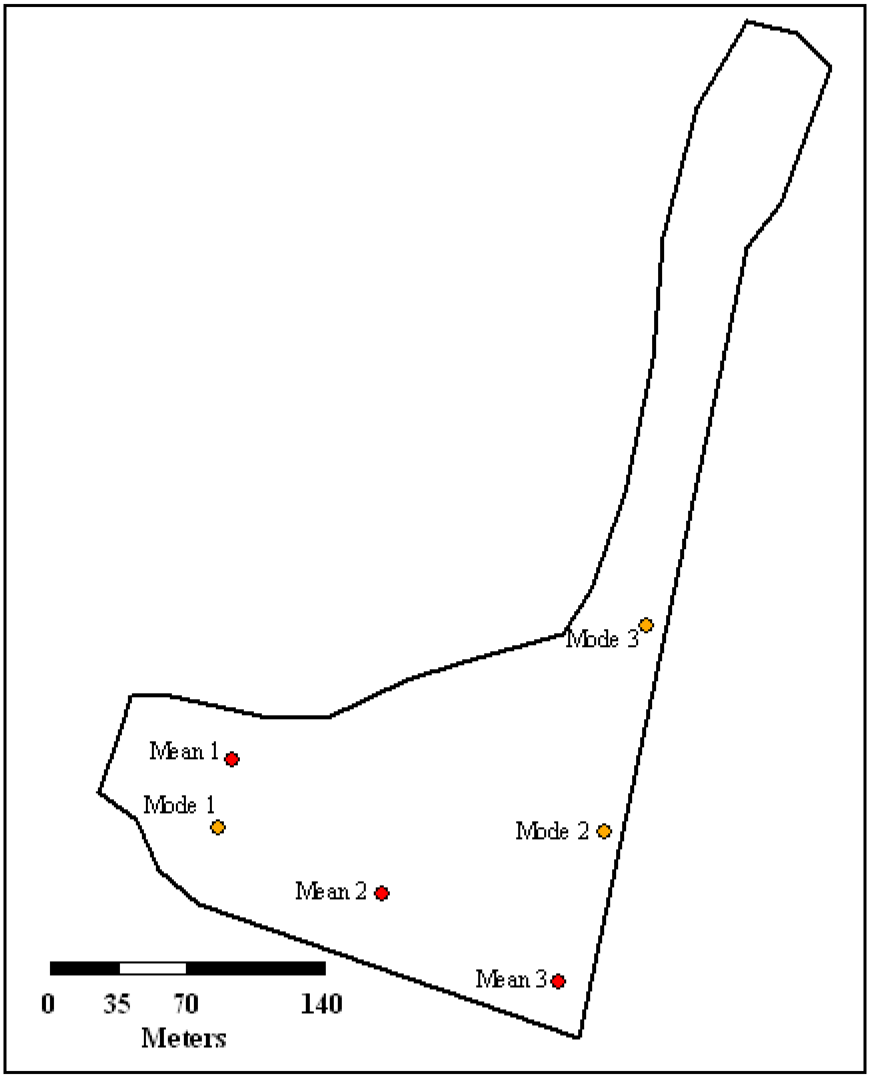


Figure 3. Description of COTMAN sampling sites

For the dryland area, COTMAN curves were generated for both sampling strategies and one combined curve using all six points. It is important to remember that the yield data used to generate the selection samples was from 2001, when the field was cultivated with sorghum. Curves generated from each method and the combined are shown in figure 4.

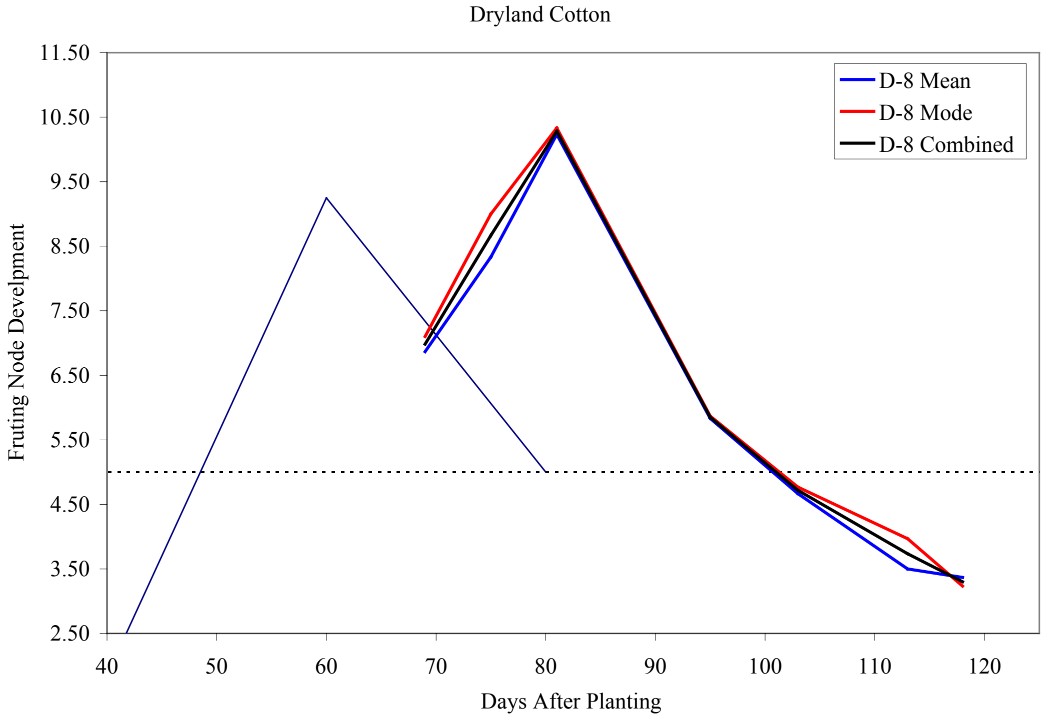


Figure 4. COTMAN curves generated for each sampling strategy and combined

For each of the strategies (mean and mode yield), curves were generated for the average of three points and also for all the combinations of two points. For the curves generated from the mean yield points, either with two or three points averaged, there is little deviation from the combined curve (figure 5). Peak number of nodes from all the curves generated is very close, with only the (1, 3) curve having around half a node less. The curves differ in cutout date (NAWF < 5) only one or two days from the combined.

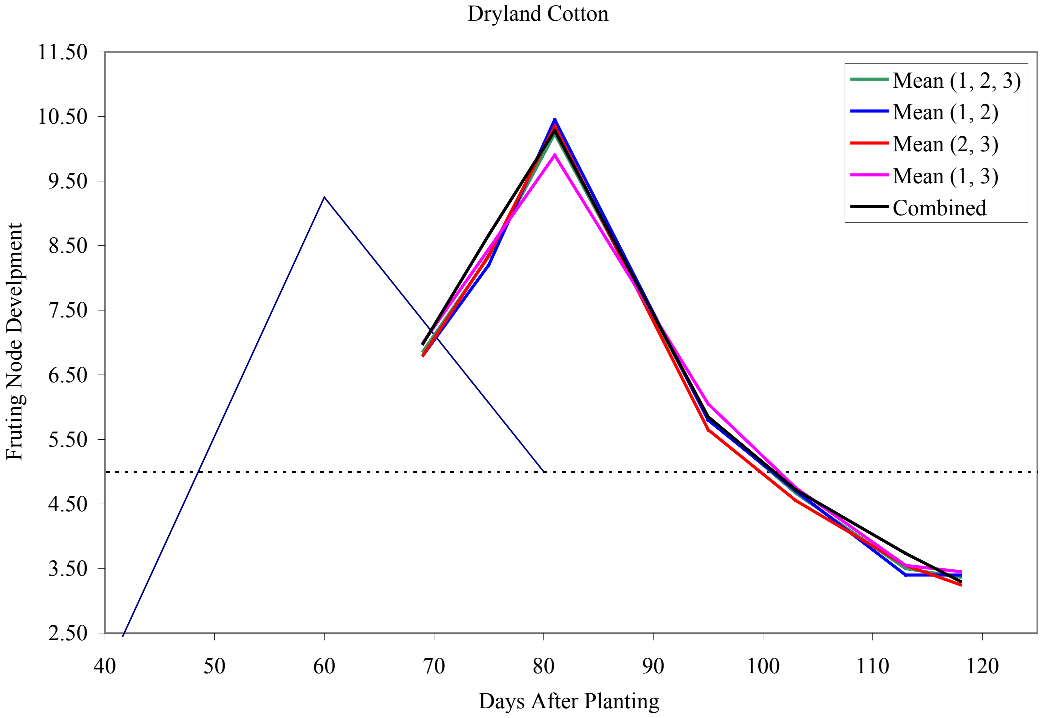


Figure 5. COTMAN curves generated for the dryland cotton from mean yield sampling

The curves generated from the mode yield points (figure 6) also follow the trend of the combined curve. Peak nodal development is approximately 10.3 nodes for all the curves. Cutout date is somewhat different, varying two to three days before and after the combined curve. The development curves generated from mean or mode yield are very similar, and management decisions made using any of these curves would vary very little.

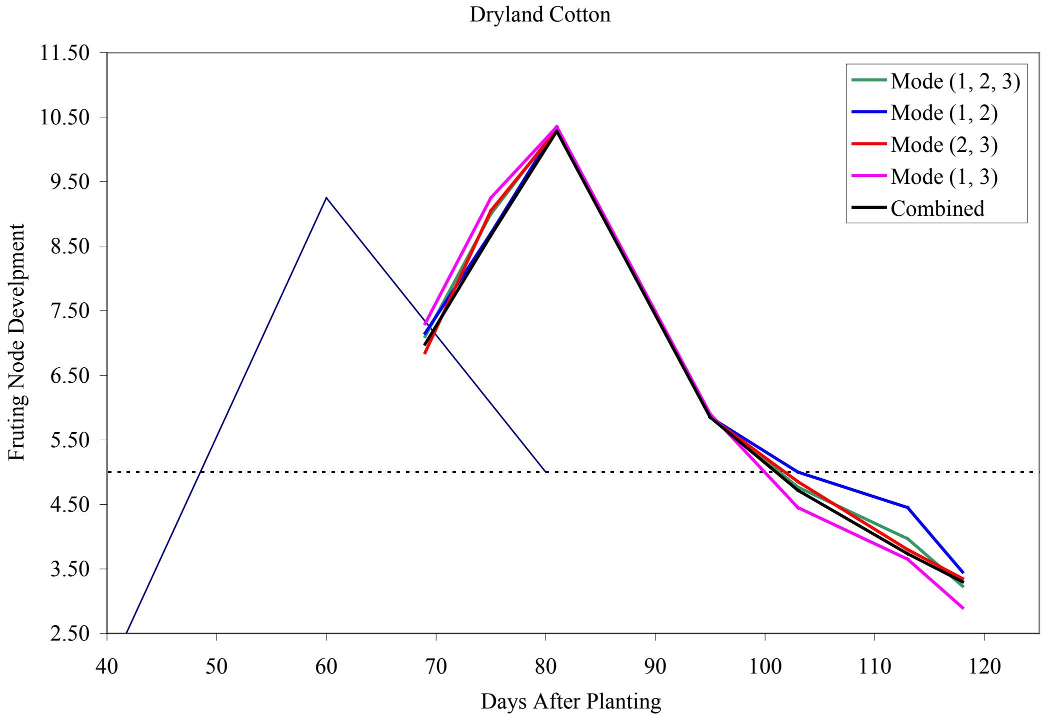


Figure 6. COTMAN curves generated for the dryland cotton from mode yield sampling

An analysis of variance (ANOVA) of the nodes above last square or nodes above white flower (depending on date) was conducted individually by days after planting (DAP) (table 2). The sampling schemes (method) did not show any significant difference at the 5% level in six of the seven days, therefore there is no significant difference in selecting sites from mean or mode yield in the dryland area. The sites (rep), however, show a significant difference at the 5% level in three of the seven dates, indicating there is more variability between the sites than the site selection method.

Table 2. Daily F-test values for dryland area from the ANOVA

		Pr > F						
		69	75	81	95	103	113	118
Dryland	D.F.	DAP	DAP	DAP	DAP	DAP	DAP	DAP
Method	1	0.5195	0.0776	0.7803	0.8029	0.5342	0.0082*	0.4282
Rep.	2	0.3436	0.2141	0.4344	0.0247*	0.0443*	0.0076*	0.0588
Method*Rep.	2	0.7675	0.798	0.386	0.1071	0.0036*	<0.0001*	0.0036*

Contrasts were established to compare pairs of sites within methods to the combined data within the field including all six sampling sites. Table 3 shows that for each date there are some combinations that show significant difference at the 5% level, but there seems not to be any specific pattern for that. The combination: mode (1, 3) had a significant difference at the 5% level on three of the seven dates from the combined data, while other combinations only had differences on one or two dates. The differences tend to appear after plants have already reached cutout (101 DAP, July 11th), when COTMAN sampling typically would have terminated in a commercial field. Before cutout, there is only one combination with a significant difference (mode (1, 3); 69 DAP). Both selection methods followed the combined curve very well, and had a comparable performance in detecting the crop changes. Table 3 indicates that the pairs of sites predicted the crop nodal development quite well using only two sites characterizing the field. This leads to the conclusion that, for this field and year, two representative sampling sites were sufficient for predicting crop development.

Table 3. Daily F-test values for the contrasts comparing combination of dryland sites

Dryland sites compared to combined	D.F.	Pr > F 69 DAP	75 DAP	81 DAP	95 DAP	103 DAP	113 DAP	118 DAP
Mean(1,2)	1	0.4743	0.0805	0.5116	0.5968	0.8833	0.0076*	0.4009
Mean(1,3)	1	0.9480	0.4119	0.1345	0.0379*	0.7692	0.1330	0.2095
Mean(2,3)	1	0.4743	0.2321	0.7926	0.0379*	0.1462	0.1330	0.6737
Mean(1,2,3)	1	0.5195	0.0776	0.7803	0.8029	0.5342	0.0082*	0.4282
Mode(1,2)	1	0.5153	0.8992	0.7926	1.0000	0.0152*	<0.0001*	0.2095
Mode(1,3)	1	0.2187	0.0302*	0.7926	0.5968	0.0220*	0.4910	0.0013*
Mode(2,3)	1	0.6024	0.1492	0.9476	1.0000	0.2434	0.5814	0.6737
Mode(1,2,3)	1	0.5195	0.0776	0.7803	0.8029	0.5342	0.0082*	0.4282

The information extracted from COTMAN is used to manage crop development. Peak nodal development and predicted cutout dates are two of the measures used for crop management. In the dryland field, curves generated from mean and mode yield show that peak nodal development occurs at 81 DAP for both method and all paired combinations. As for cutout dates, the combined curve suggest that cutout is reached 101 DAP. The paired combinations and the methods seem to track this quite well, as can be seen on table 4.

Table 4. Predicted cutout dates for the dryland field

	Predicted cutout (DAP)	Deviation in days from combined
Mean (1, 2)	101	0
Mean (2, 3)	100	-1
Mean (1, 3)	101	0
Mean (1, 2, 3)	101	0
Mode (1, 2)	103	2
Mode (2, 3)	102	1
Mode (1, 3)	100	-1
Mode (1, 2, 3)	101	0

IRRIGATED

The irrigated field had much more variability than the dryland. Plant height was highly variable, and soil conditions throughout the field also were variable. While the eastern portion of the field was more uniform, the western part of the field contained both tall, vigorous plants and very short plants. The irrigated field contains sandy spots, where plant development was slow due to poor water availability. Three of the sampling points were located in a variable rate mepiquat chloride experimental area, but this should not have affected the data, as mepiquat chloride was applied only when plants were close to cutout. Two of the points were located in the area of fixed rate of mepiquat chloride, and the third one was located in between the variable rate and a control treatment.

Figure 7 represents site distribution in the field. It is shown to aid the understanding the variability of the COTMAN curves. The clustering of data in the northwest and northeast portions of the field is attributed to the site selection procedure. Some data points are more scattered and were also sites that represented the field average. An analysis of the points within the clusters (NW and NE) is done to understand within method variability. The methods using height and yield data had similar results to the points selected by the expert. A difference in the methods is that the expert sites were selected based on field observations a few weeks after emergence in 2003, while the height and yield methods used GIS and historical data for site selection.

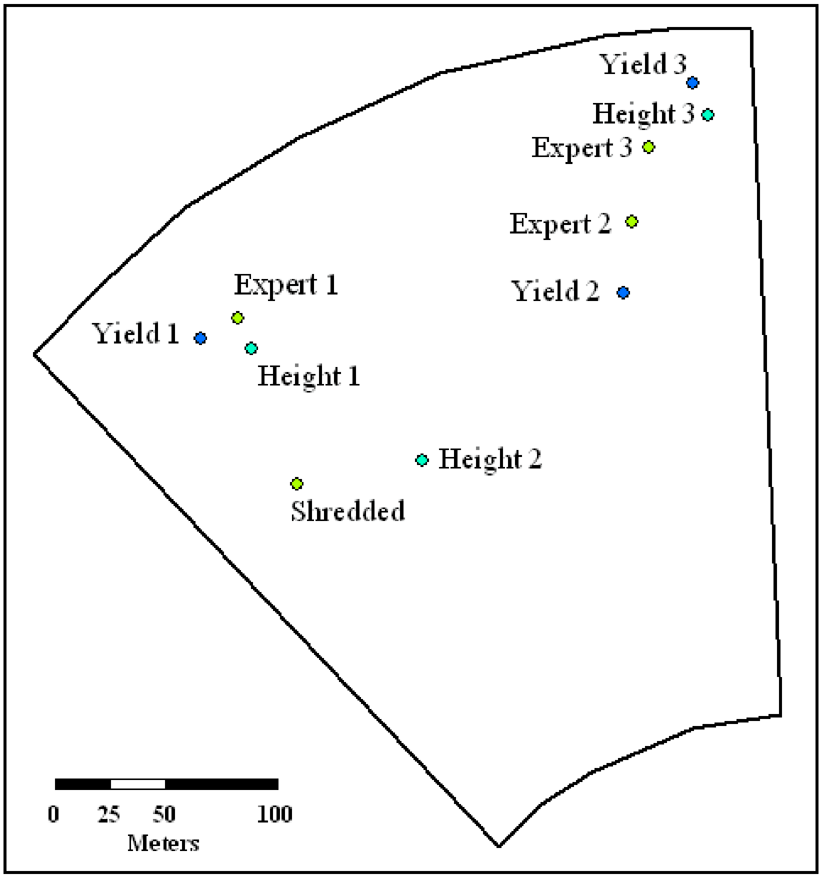


Figure 7. Location and labeling of COTMAN sampling sites in the irrigated field

COTMAN curves were generated for all three sampling strategies and one curve was generated for the combination of all data (figure 8). It is interesting to note that the curves generated from sites selected from height have more nodes at peak development and predict a shorter season. Sites elected from yield predict a longer season and fewer nodes at peak development.

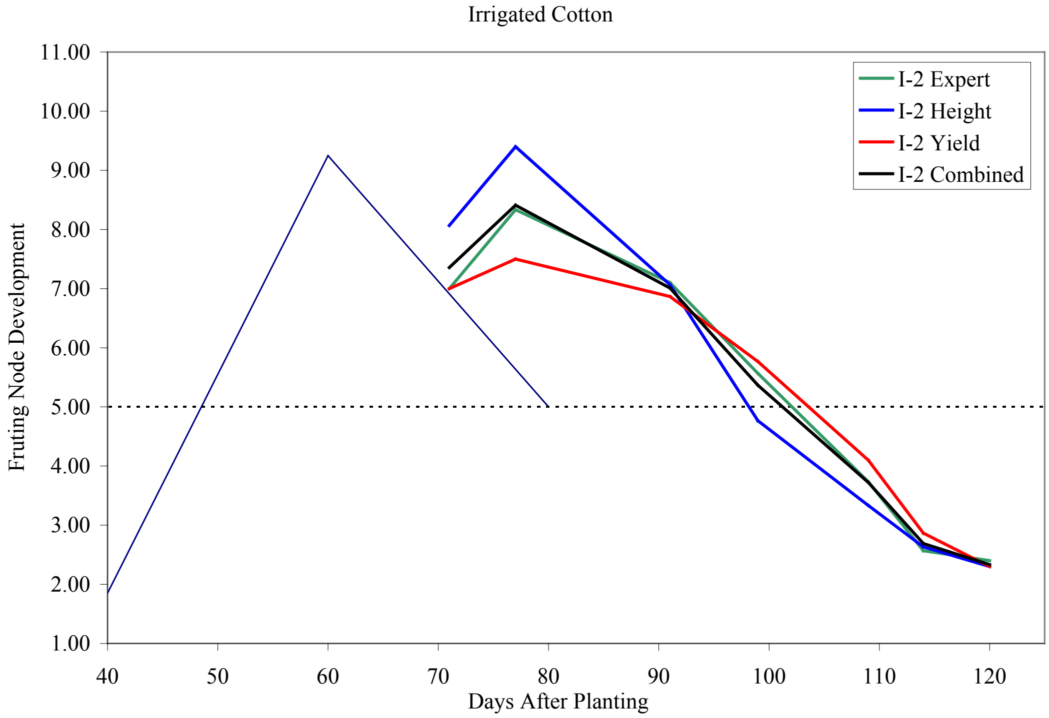


Figure 8. COTMAN curves generated for each sampling strategy and combined

Each of the three strategies had curves plotted in COTMAN. Pairs of sites within the method were also selected for analysis. Figure 9 shows the curves generated from the sites selected by the expert in 2003. Except for the combination expert (1,2) the other three curves seem to follow the combined curve very well. The combination expert (1, 2) seems to lag behind in nodal development and take a longer time to flower, which explains the flatness of the curve from the second to the third date of data collection. Peak number of nodes varies about 0.8 nodes above and below the combined curve. Cutout dates are consistent throughout the sites, except for the combination expert (1, 2).

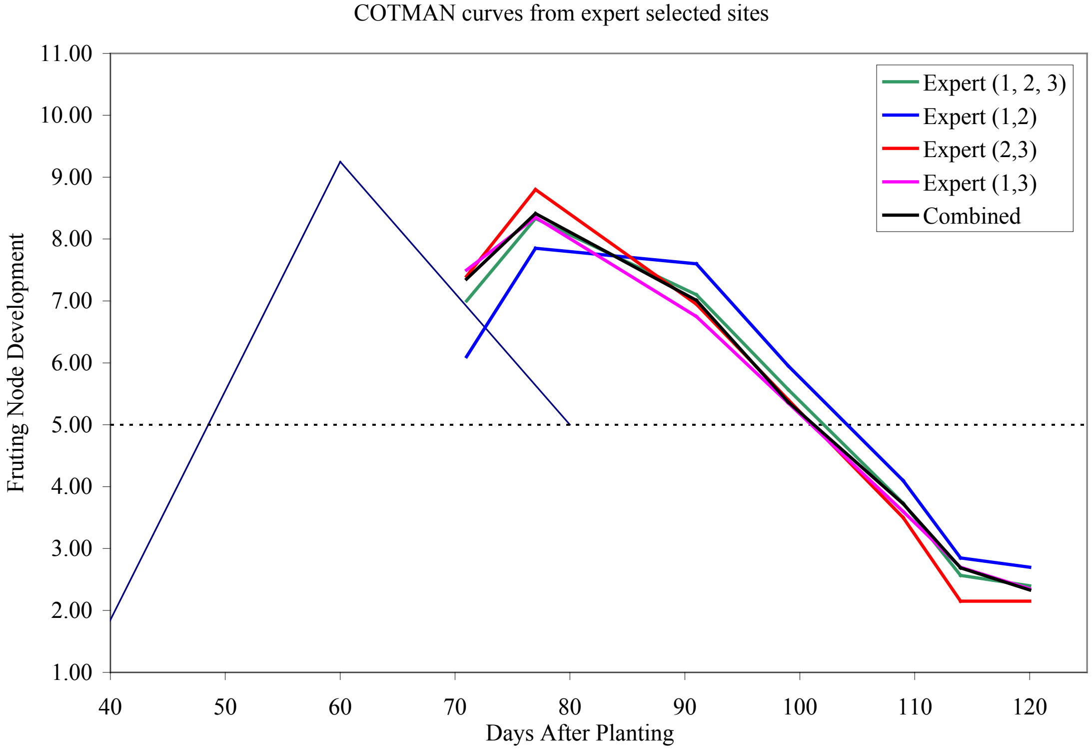


Figure 9. COTMAN curves generated from combination of expert sites and all data

The curves generated from height (figure 10) seem to follow the trend of the combined curve. Initially, there are more nodes above the last square on the plants compared to the combined data. The curves approach the trend of the combined on the first day of NAWF count. The combination height (2, 3) has approximately two more nodes than the combined, while all other height combinations have around one node more than the combined data. Cutout dates for the sites selected from height tend to be earlier than the combined, therefore suggesting an earlier termination, and a shorter season.

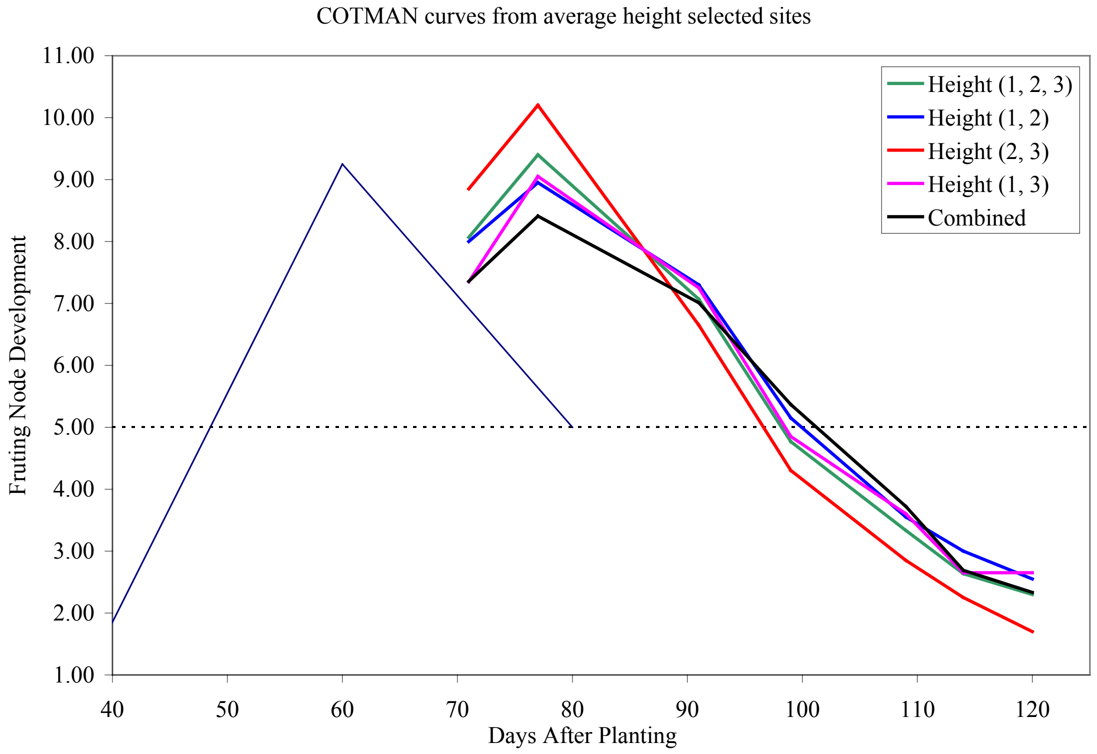


Figure 10. COTMAN curves generated from combination of height sites and all data

The curves generated from mean yield (figure 11) had a slower nodal development than the combined curve, with one of the combinations reaching peak node development much later than all others. It is likely that the true peak was earlier and higher than that shown for yield (1,2), but field conditions prevented sampling during that period. As in the other figures, once peak node development is reached and NAWF is counted, the variability seems to diminish somewhat. The data from yield had, in most cases, one node less than the combined data in the first two dates of data collection. Cutout dates for the sites selected from yield tend to be later than the combined, therefore suggesting a later termination, and a longer season.

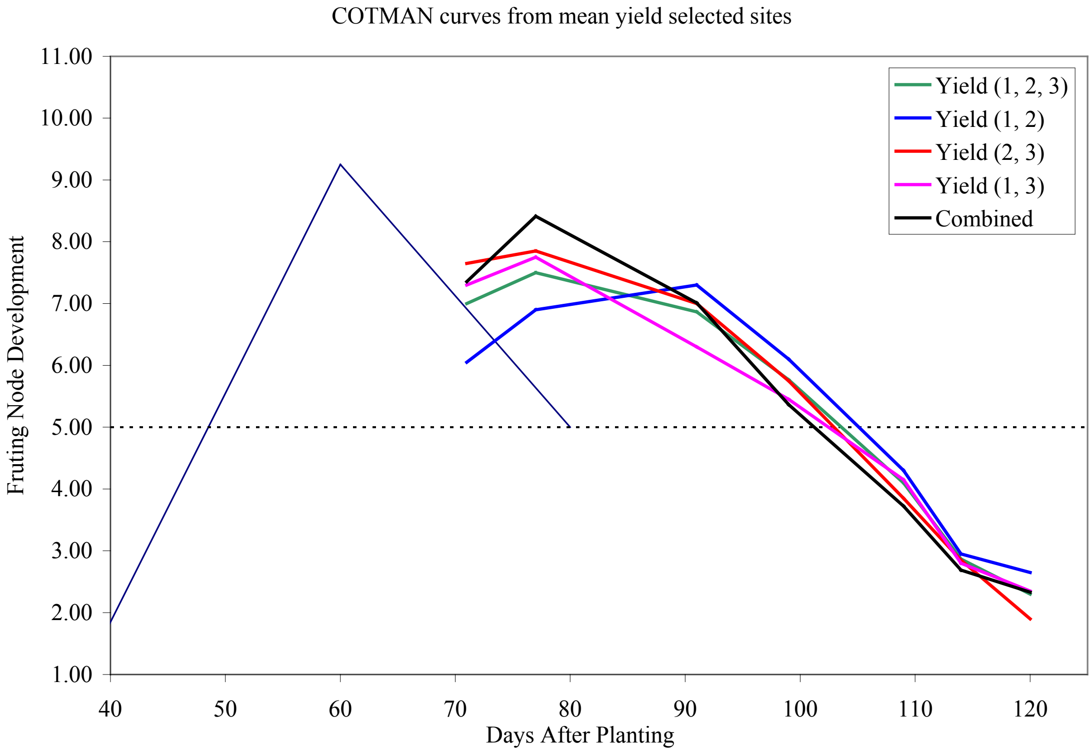


Figure 11. COTMAN curves generated from combination of yield sites and all data

Areas of average height are not necessarily the same as areas of average yield, and while the data extracted from height shows a faster development, the data from yield shows a delayed development. Height data was collected in 2002 and 2003 and used for site selection. Yield data was from 2001, 2002 and 2003. A histogram of plant heights (6/20/2003) is shown on figure 12 to elucidate distribution of data. Figure 13 shows a histogram distribution of yield and also a distribution of yield points located within 10 m of average height points on 6/20/2003. Even though the yield histogram is similar for the whole dataset and the areas selected from average height, the height histogram shows a different distribution. The multi-modality of the height histogram does not agree with the yield and could be the reason of the differences in the development curves.

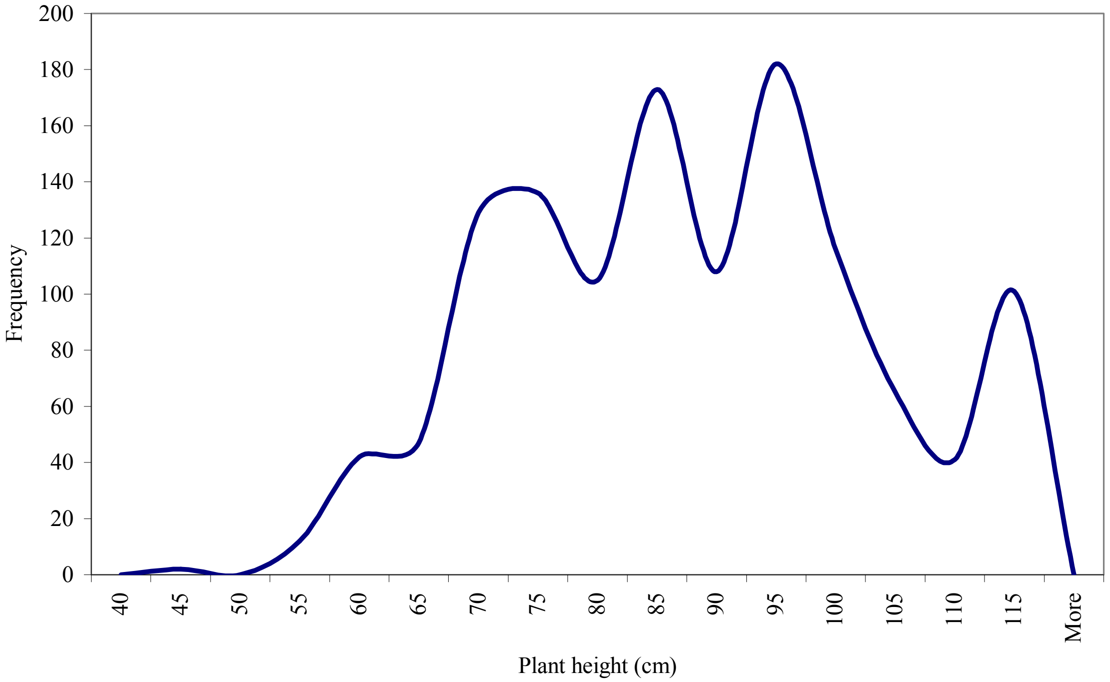


Figure 12. Histogram of height distribution on 6/20/03

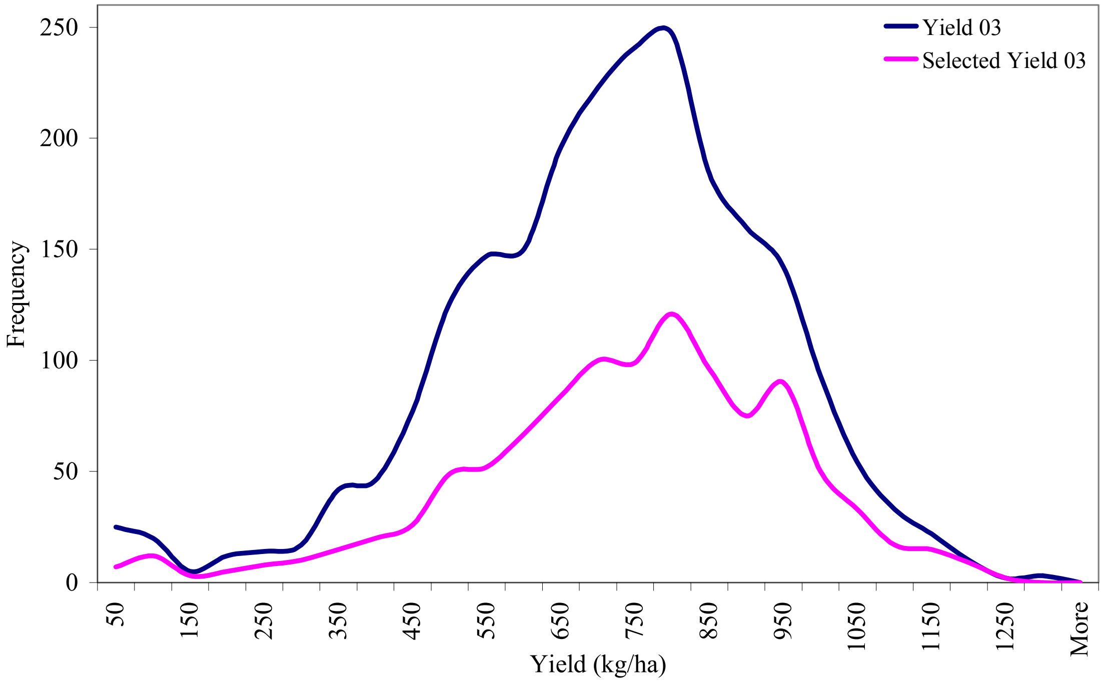


Figure 13. Histogram of yield distribution from 2003

An ANOVA was conducted for each individual date (table 5). In the case where interaction between effects was not considered, the sampling schemes (method) did show significant difference at the 5% level in four of the seven dates of data collection, indicating that there is significant difference between the different sampling schemes. The sites (rep.) however show a significant difference at the 5% level in all seven days, indicating that there is more variability between the sites than between selection methods (similar to the dryland field). The I-2 field is highly variable, with some areas producing tall vigorous plants and other areas consistently producing poor stands and highly stressed plants. With this range of conditions, the collection of sites with the field average condition may not be geographically stable from year to year. Yield and height data from 2004 was used to check for consistency of site selection. Height data indicated that the sites selected from 2002 and 2003 would have been similar if the 2004 data were used. Yield data was only available for the western portion of the field, but it does also indicate agreement with yield data from previous years.

Table 5. Daily F-test values for irrigated area from the ANOVA

		Pr > F						
Irrigated	D.F.	71 DAP	77 DAP	91 DAP	99 DAP	109 DAP	114 DAP	120 DAP
Method	2	0.0007*	<.0001*	0.1883	<.0001*	0.0034*	0.1692	0.8664
Rep.	2	<.0001*	<.0001*	<.0001*	<.0001*	<.0001*	<.0001*	<.0001*
Method*Rep.	4	<.0001*	0.2593	<.0001*	0.0005*	0.1222	0.0057*	0.076

Contrasts were established to compare pairs of sites within methods to the combined data within the field including all nine sampling sites. Each method was decomposed and all the pair combinations within methods were compared to the combined data.

For the sampling sites selected from yield, there was a significant difference from the combined data on six dates for one of the sites (table 6), while there was a significant difference in two, three or four of the seven dates for the other three comparisons.

For the data selected from average height, there was one comparison with seven out of seven significant differences (table 6) and the other three comparisons had significant differences in two, three or four of the seven dates.

The sites selected by the expert in 2003 had the least differences from the combined data (table 6). One of the combinations had five out of seven possible differences, while the other three comparisons had either one or two significant differences out of seven possible ones. One of the sites selected by the expert, though was shredded due to poor cotton stand and weed infestation, had it not been shredded, the comparisons would likely have been quite different.

Table 6. Daily F-test values for the contrasts comparing combination of irrigated sites

Irrigated sites compared to combined	D.F.	Pr > F 71 DAP	77 DAP	91 DAP	99 DAP	109 DAP	114 DAP	120 DAP
Expert(1,2)	1	<0.0001*	0.0619	<0.0001*	<0.0001*	0.0271*	0.2056	0.0286*
Expert(1,3)	1	0.5408	0.8371	0.0144*	0.8859	0.4687	0.9301	0.9196
Expert(2,3)	1	0.8506	0.1931	0.5599	0.7741	0.1893	<0.0001*	0.2685
Expert(1,2,3)	1	0.0489*	0.7293	0.2633	0.0249*	0.9304	0.2040	0.5935
Height(1,2)	1	0.0076*	0.0727	0.0070*	0.0648	0.3080	0.0158*	0.1917
Height(1,3)	1	0.9812	0.0341*	0.0247*	<0.0001*	0.4687	0.7589	0.0578
Height(2,3)	1	<0.0001*	<0.0001*	0.0009*	<0.0001*	<0.0001*	0.0008*	0.0002*
Height(1,2,3)	1	0.0001*	<0.0001*	0.4835	<0.0001*	0.0030*	0.5621	0.7894
Yield(1,2)	1	<0.0001*	<0.0001*	0.0070*	<0.0001*	0.0009*	0.0418*	0.0578
Yield(1,3)	1	0.8139	0.0284*	<0.0001*	0.4736	0.0127*	0.3814	0.9196
Yield(2,3)	1	0.2142	0.0619	0.9155	0.0014*	0.4488	0.2056	0.0101*
Yield(1,2,3)	1	0.0489*	0.0001*	0.0709	<0.0001*	0.0038*	0.0661	0.7894

Even though none of the sampling methods was effectively comparable to the curves generated from the combined data, it is interesting to note that they did track the development curve of the crop. The peak nodal development occurred at 77 DAP and only one of the paired sites (yield 1, 2) indicates that peak nodal development occurred later (91 DAP).

The combined data indicated cutout was reached at 101 DAP. The variation in predicted cutout dates for each method and within the pairs of sites for each method can be seen on table 7. The data from two site curves for the expert, height and yield selection methods resulted in cutout date predictions that differed from the combined by 3, -4 and 4 days respectively. As for peak nodal development, all but one of the combinations agree that it was achieved at 77 DAP.

Table 7. Predicted cutout dates for the irrigated field

	Peak nodal development (DAP)	Predicted cutout (DAP)	Deviation in days from combined
Expert (1,2)	77	104	3
Expert (2,3)	77	101	0
Expert (1,3)	77	101	0
Expert (1, 2, 3)	77	102	1
Height (1, 2)	77	100	-1
Height (2, 3)	77	97	-4
Height (1, 3)	77	99	-3
Height (1, 2, 3)	77	98	-3
Yield (1, 2)	91	105	4
Yield (2, 3)	77	103	2
Yield (1, 3)	77	102	1
Yield (1, 2, 3)	77	104	3

Within the irrigated field, there were sites selected by different methods that were clustered together. One of the clusters was on the northeastern part of the field (NE), and was composed by sites: expert 3, height 3 and yield 3; that were from 18 to 30 meters apart. For the northwestern cluster (NW), the used sites were: expert 1, height 1 and yield 1; these points were from 15 to 23 meters apart. The NW portion of the field was also used in a variable rate mepiquat chloride experiment. The sites expert 1 and yield 1 were located in a fixed rate area, while height 1 site was located on the boundary between a control and a variable rate area. The NE area received a fixed rate. COTMAN curves were generated and can be seen on figure 14.

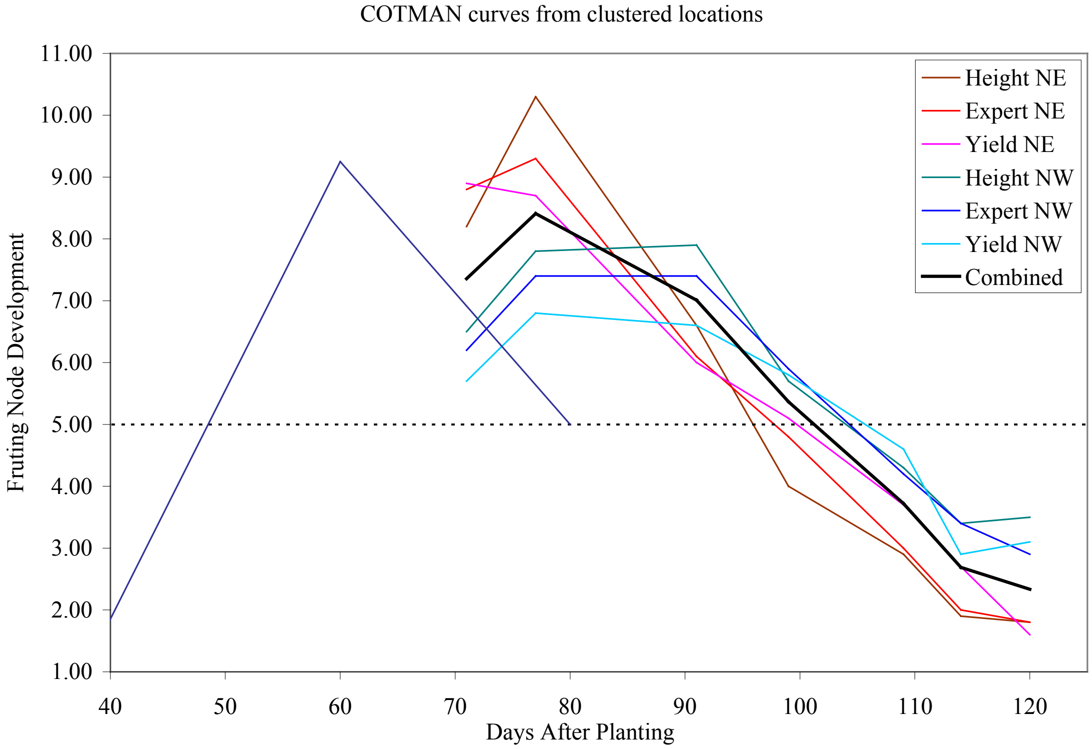


Figure 14. COTMAN curves for the NE and NW cluster of sampling sites

It is interesting to note that the development curves within the NE or NW regions agree in shape, but not in nodal development. The NE curves suggest peak nodal development at 77 DAP, while the NW curves suggest that peak nodal development was somewhere between 77 and 91 DAP. The suggested cutout date (NAWF < 5) for each one of the sites, and peak nodal development are shown on table 8.

Table 8. Predicted cutout day by method and cluster

Location	Peak nodal development (DAP)	Predicted cutout (DAP)	Deviation (days) from combined
Expert 1 NW	77	104	3
Height 1 NW	91	104	3
Yield 1 NW	77	106	5
Expert 3 NE	77	98	-3
Height 3NE	77	96	-5
Yield 3 NE	71	100	-1
Combined	77	101	

All the sites in the NW suggest cutout between 104 and 106 DAP, while the NE sites suggest that cutout is reached between 96 and 100 DAP. The combined curve from all nine sites suggested cutout to be at 101 DAP, which is about the average of the NE and NW. It is interesting to note that the development curves are similar for each region, regardless of selection method. Figure 14 and table 8 confirm that there is more variability between sites than site selection method.

Table 9 shows peak nodal development and predicted cutout dates for combinations of sites from different methods.

Table 9. Predicted cutout and peak nodal development for combination of sites

	Peak nodal development (DAP)	Predicted cutout (DAP)	Deviation (days) from combined
Height 1, Yield 1	77	105	4
Height 1, Yield 2	91	105	4
Height 1, Yield 3	77	102	1
Height 2, Yield 1	77	100	-1
Height 2, Yield 2	77	101	0
Height 2, Yield 3	77	98	-3
Height 3, Yield 1	77	99	-2
Height 3, Yield 2	77	100	-1
Height 3, Yield 3	77	97	-4
Combined	77	101	

When doing an analysis of pairs of sites to the combined, one can see that all but one of the combinations agrees in peak nodal development. As for the predicted cutout dates, the combinations of sites from different methods indicate variations from –4 to 4 days difference. There does not seem to be a specific pattern for that, but all the combinations that include the site height 1 indicate a longer season, while all those that have height 3 indicate a shorter season.

When comparing peak nodal development and cutout dates from the combination of sites within the methods and between methods, the differences are attributed mainly to the sites themselves rather than the selection method. The data from table 9 confirms this, and table 8 shows the differences in cutout dates that are attributed to the location of the sampling sites. Within a more homogeneous area, the sites, independent of selection method have a similar curve, with management decisions that would only be affected by a change in cutout date.

The dryland and irrigated areas indicate that site-specific data can be used for selection of representative and consistent sites within the field. In areas of higher homogeneity COTMAN sampling can decrease without loss of information and possibly 2 sites can be used to characterize the field. In areas of higher variability though, such as the irrigated area, the most important thing is to have at least one point for every area of different growing conditions.

SUMMARY

The use of historical data can assist farmers in selecting representative areas within the field. For the dryland field, it was seen that selecting sites of either mean or mode of historical yield resulted in very similar development curves. While both methods gave similar results, it is important to remember that the mean value can be affected by extreme values, and therefore the mode might be more representative. The ability to use historical grain yield maps to select a reduced number of COTMAN sampling sites has significant potential for reducing the cost of using COTMAN. Since this field was somewhat uniform, it could be characterized with only two points rather than the four suggested by COTMAN.

For the irrigated field, the main difference between the methods (yield and height) would be the predicted cutout date, since all methods suggested peak nodal development being achieved on the same date. The cluster analysis (NE and NW) show that the methods tracked the same development, but with differences between site location.

For highly variable fields the number of COTMAN sampling sites should deal with the variability within the field. Uniform areas could possibly be represented by one point. While COTMAN curves are used to characterize the field average, if the field is very heterogeneous, the curve will not be representative. A possible solution for this would be to do sampling within management zones, or areas of higher uniformity.

Management decisions are different from farm to farm and while some target minimum cost, others target maximum profitability. Interpretation of the COTMAN data must aid both scenarios. Curves must represent field conditions and higher heterogeneity will imply in either more data collection (within more uniform areas) or decreased quality of information. In a heterogeneous field, number of sites will depend on management practices, in which, if there is localized management, sampling should be conducted in the same fashion.

The use of site-specific data, such as yield or height maps, can aid producers in selecting representative sites within the field. This study shows that the method of site selection does not matter as much as the sites themselves. The cluster analysis showed that different methods tracked the same curve in every location, but also tracked differences between locations. Combinations of sites from different methods also yielded similar curves as the ones generated within the methods, supporting that the site selection method does not affect the quality of the data. Sampling should focus on detecting differences within the field and for that it is suggested at least one sampling point for each area of different conditions. Within more uniform areas, one or two sites are sufficient for characterizing cotton growth. If the management decisions will be uniform for the whole field it is suggested that one COTMAN curve is generates from at least one site from each uniform area in the field.

CONCLUSIONS

The availability of site-specific datasets for the field can aid in COTMAN site selection. Using data yield or height data should not affect site selection procedures, and management decisions with fewer sampling sites would not be affected. Areas of high uniformity can be characterized with one or two points, and highly variable fields should have at least one point for each heterogeneous area.

Site-specific data, such as yield or height, are comparable for selecting representative sites within the field. Historical data confirms that sites are consistently selected from year to year independent of site selection method. This can aid producers in selecting representative COTMAN sites, while reducing sampling time and costs.

FUTURE RESEARCH

The use of site-specific data for COTMAN site selection must be further tested in other areas of the country to verify the validity of the research. A suggested approach is to acquire historical information, such as previous years yield maps, to select COTMAN sampling sites. COTMAN data would then be collected in the sites selected from historical data and from the sites selected by farmers/researchers. Development curves would then be compared.

Another topic for research would be to select COTMAN sampling sites within management zones. Theses zones would have to be determined by the farmer/researcher and sites within the management zones would be used to manage the crop according to the specific needs of each zone. COTMAN curves could be plotted within the zones and with the combined data to check if it represents the average field condition.

CHAPTER III

REAL TIME VARIABLE RATE APPLICATION OF MEPIQUAT CHLORIDE

INTRODUCTION

Although cotton is grown as an annual crop, it is a perennial and this affects the plant's response to stress. When undergoing stress, the plant will maintain its vegetative growth while diminishing production. To effectively maintain cotton plants at a tolerable height, producers use a plant growth regulator, mepiquat chloride.

The need for mepiquat chloride will vary according to variety, soil, water stress, solar irradiance and other factors. Farmers use mepiquat chloride to reduce vegetative growth so that they get a more uniform plant height, and therefore increase harvest efficiency.

Traditionally producers have applied a fixed rate of mepiquat chloride throughout the field, based on information collected by the producer. The application rate of mepiquat chloride could be determined by a variety of methods. The product label suggests a variety of rates according to crop development stage and geographical location of the crop. Another method for determining rates is the mepiquat chloride rate and timing (MEPRT) stick. Average internode length of the top-most five nodes (ALT5) must be measured in the field and, according to that, an application rate. The limitation of this method though is that it only considers the ALT5 for determining the rate. Associated with the MEPRT stick is software that will assist in determining the application rate. The MEPRT software uses information such as plant height and average internode length to estimate plant biomass, suggesting an application rate that will optimize the efficiency of the growth regulator, by trying to achieve the optimal concentration of the product in the plant, and using the software is preferable to just using the rate indicated by the MEPRT stick.

With the advance of precision agriculture and the development of new farming equipment, it has become possible to apply chemicals in variable rates according to necessity. Once one can characterize the spatial variability within the field, management decisions can be made and application of chemicals, such as crop growth regulators, can be done more effectively.

Field variability can be assessed by various different methods. Use of remotely sensed images will allow for estimation of cotton biomass by correlating it with vegetation indices such as NDVI. Application rates can be then determined by using the biomass as an input for the MEPRT software and therefore calculation of an application rate.

Another alternative to blanket application of mepiquat is to vary the rate according to the crop height, in which case taller plants would receive a higher rate, while shorter plants, a lower application rate. This has been previously evaluated using two approaches: manual rate adjustment by a driver according to visual evaluation of the plant height, and a continuous system where the mepiquat chloride rate was adjusted in response to plant height measured by an on-sprayer sensor (HMAP).

Varying the application rate based on the plant height has a few implications. If the producer has to go in the field to acquire data for rate calculation, it will be limited by the points where the producer collects data and estimates the average plant height. Accurate characterization of the whole field average conditions can be difficult, and still ignores variation in plant status that is always present. In the second case, where biomass is extracted either by remotely sensed images or by the HMAP system, the method is limited by using height information, which does not consider the current growth rate of the plant, only its size.

An optimum technique though would be one that collected height information for the whole field, and therefore minimized the guessing of average conditions. It would also have to be able to determine the rate of growth of the plants, so that it would address the problem of a short plants with high rates of growth and tall plants with a low rate of growth. It would also have to calculate the biomass in real-time and therefore determine the optimum growth rate.

By applying a variable rate of mepiquat chloride, one can more effectively control plant height throughout the field, and therefore not only minimize mepiquat use, but also have a more uniform field.

The *hypothesis* of this study is that, by utilizing a variable rate mepiquat application, one will diminish plant height and variability in the field. The objectives are to:

- Evaluate the performance of the height estimation algorithm;
- Evaluate the rate of growth algorithm;

- Implement and test the real time variable rate application system in the field; and
- Establish if variable rate application of mepiquat chloride significantly reduces the resulting plant height.

LITERATURE REVIEW

Cotton is an indeterminate, perennial crop that is grown as an annual. The complex plant structure and indeterminate growth make crop management more complicated than many other crops. The plant must have a balance between vegetative and reproductive growth, where there is enough vegetative growth to provide adequate carbohydrate supply for fruit development, but not excessive vegetative growth that would inhibit fruit development (Kerby et al., 1997).

Mepiquat chloride has been used to contain the vegetative growth of cotton by decreasing leaf area of new leaves and restricting plant height increases (Kerby, 1985). In 35 replicated experiments in the San Joaquin Valley of California conducted over a five year period, application of mepiquat chloride did not show a consistent increase in yield, but did reduce plant height, increased percent of final harvestable bolls by 5% and reduced main stem nodes by one (Kerby, 1985).

Cothren (1979) affirmed that, in a controlled environment, mepiquat chloride reduced water uptake by 44% and those plants exhibited reduced vegetative growth and darker green color within five days after application. Mepiquat chloride has a reported potential to increase fruit retention in cotton and acts as an anti-gibberelin. It inhibits two consecutive enzymes in the gibberelin biosynthesis pathway. Reduced internode length causes shorter plants that are more compact with reduced leaf expansion (Cothren and Oosterhuis, 1993).

Different studies show different effects on yields from the use of mepiquat chloride. Siddique et al. (2002) reported decrease of plant height by 26%, with increase in yield and yield attributes. Kerby et al. (1986) reports that mepiquat chloride decreased number of bolls by 3.1%, with a higher retention of early boll load, not increasing yield for most of the four-year experiment. Biles and Cothren (2001), in a study where they tested flowering and yield response of cotton to mepiquat chloride and PGR-IV, concluded that application of mepiquat chloride and PGR-IV increased the rate of flowering, boll numbers and yield. Kennedy and Hutchinson (2001) reported that during a three-year study under different tillage systems, higher yield was related to faster, early season crop growth, which can be promoted by mepiquat chloride. Even though the effect on yield is not consistent, producers continue to use mepiquat chloride, not only for reducing vegetative growth but also to promote early maturity (Reddy et al. 1992).

The concentration of mepiquat chloride in the plant has an effect on growth. Landivar et al. (1995) reported that a concentration of 12 mg/kg would reduce leaf expansion area to 80% and main stem elongation to 47%. By determining the optimal application rate, one can optimize cost-effectiveness of mepiquat chloride. To predict plant height, Landivar et al. (1996) created the average length technique of the uppermost five internodes (ALT5). The ALT5 is based on the assumption that individual internodes have their maximum length 12 to 15 days after initiation and the time course of plant height development follows a sigmoidal growth pattern. The ALT5 measurements were more sensitive in detecting changes in growth rate induced by use of mepiquat chloride than using the height-to-node ratio for the whole plant.

By monitoring the number of main stem nodes above the sympodial branch bearing white flower in the first position from the main axis (NAWF), one can determine crop development. Based on individual boll measurements, potential economic value of flowers decline as NAWF approach five (Bourland et al. 1992). NAWF equals five can be defined as the flowering date of the last effective bolls, therefore being a target for management strategies.

To determine the mepiquat chloride application rate, Landivar (1998) developed the mepiquat chloride rate and timing (MEPRT) system. It consists of the MEPRT stick (Landivar et al. 1996) to determine if application is needed and the MEPRT software that determines the rate of application. The MEPRT stick measures the average internode length of the uppermost five internodes, and works best if used from match-head square stage until two weeks after first bloom. If the plants have an average internode length that is smaller than 3.6 cm, then mepiquat chloride is not needed, but if the average internode length is greater than that, the MEPRT software should be used. Another approach using the MEPRT stick would be to calculate an application rate solely on the average internode length of the top five nodes. This technique has been used but is not optimal. The MEPRT software, associated with the stick, calculates the rate of application by calculating the amount of mepiquat chloride needed to achieve the desired concentration. The program uses plant density, main stem nodes and plant height to estimate plant weight. This is based on a strong correlation between plant height and weight during vegetative growth.

Ground or air broadcast spray have usually been the application method of mepiquat chloride. Alternatives to this technology have become available in the past few years. Stewart et al. (2001b) suggested the use of a wick delivery system, that wiped the growth regulator on the top three to four nodes of the plant, and since it was a low volume application that was more effective, allowed fewer refilling of the application tank. Stewart et al. (2001a) affirmed that wick application was more effective and favorable to an early application in non-uniform fields, since only the tallest plants would be affected if there were a height differential. This system does not consider plant growth rate, and tall plants with a low growth rate will receive an application rate, while shorter plants that are vigorously growing will receive no mepiquat chloride at all.

While there are some fields that are quite uniform, many of the cotton fields have substantial variability in vegetative growth, and therefore plant height. Some areas might have stressed plants, while others might have very vigorous plants that need a growth regulator. Munier et al. (1993) suggested the application of mepiquat chloride at a variable rate. Taller plants would receive a higher rate, while shorter plants would receive a lower rate of mepiquat chloride. While distinction of small, medium and large plants was done visually, there are more modern approaches that can take in account measured plant height (Thurman and Heiniger, 1999) and even plant growth rate (Geiger, 2004).

Thurman and Heiniger (1999) suggested that a variable rate application of mepiquat chloride would only be justified if it were practical and: (a) improved field profitability, (b) improved mepiquat efficiency and (c) increased environmental stewardship. It is also important that there is crop variability to make variable rate applications effective. In the study, the authors manually took plant height samples on a 0.30 ha (0.75 ac) grid and on a 0.1 ha (0.25 ac) grid, each sample consisted of five plants of which the height was be averaged. Variogram analysis through a spherical model was done to determine spatial variability and kriging used to estimate values in the field. Sampling was done weekly from first bloom to cutout (NAWF < 5). The authors concluded that there was enough variability in the field to justify variable rate practices.

Geiger (2004) proposed the use of the rate of growth (RoG) of cotton to determine mepiquat chloride application rates. The system called HMAP developed by Searcy and Beck (2000) was used to measure plant height in the field during sprayer operations. The system would measure plant height and record GPS locations, resulting in a height map of the field. The program developed by Beck (2001) generated a real-time mepiquat chloride application rate according to the height of the plant. Geiger (2004) implemented a system, which used historical plant height to calculate a differential growth. This differential, divided by the number of days since the previous height measurement, would output the rate of growth (cm/day) and therefore trigger the MEPRT program that would calculate an appropriate application rate of mepiquat chloride. The RoG approach is more refined than just considering the height. In the latter case, taller plants, independent of their current growing status, would always receive a high application rate, while the short plants would receive a smaller or no rate. With the RoG system, the growth rate is considered and a tall plant that is not growing will not receive as much mepiquat as a short plant that has a high RoG. The system developed by Geiger (2004) was not tested in the field. Simulation done in the laboratory was used to test the efficiency in detecting change in rate of growth with promising results. The simulated plant rows consisted of a wooden course, with varying height, which would block all the beams. In the field thought, plant stand does not necessarily block all the beams and the soil is not as stable as the concrete where the system was tested previously.

MATERIAL AND METHODS

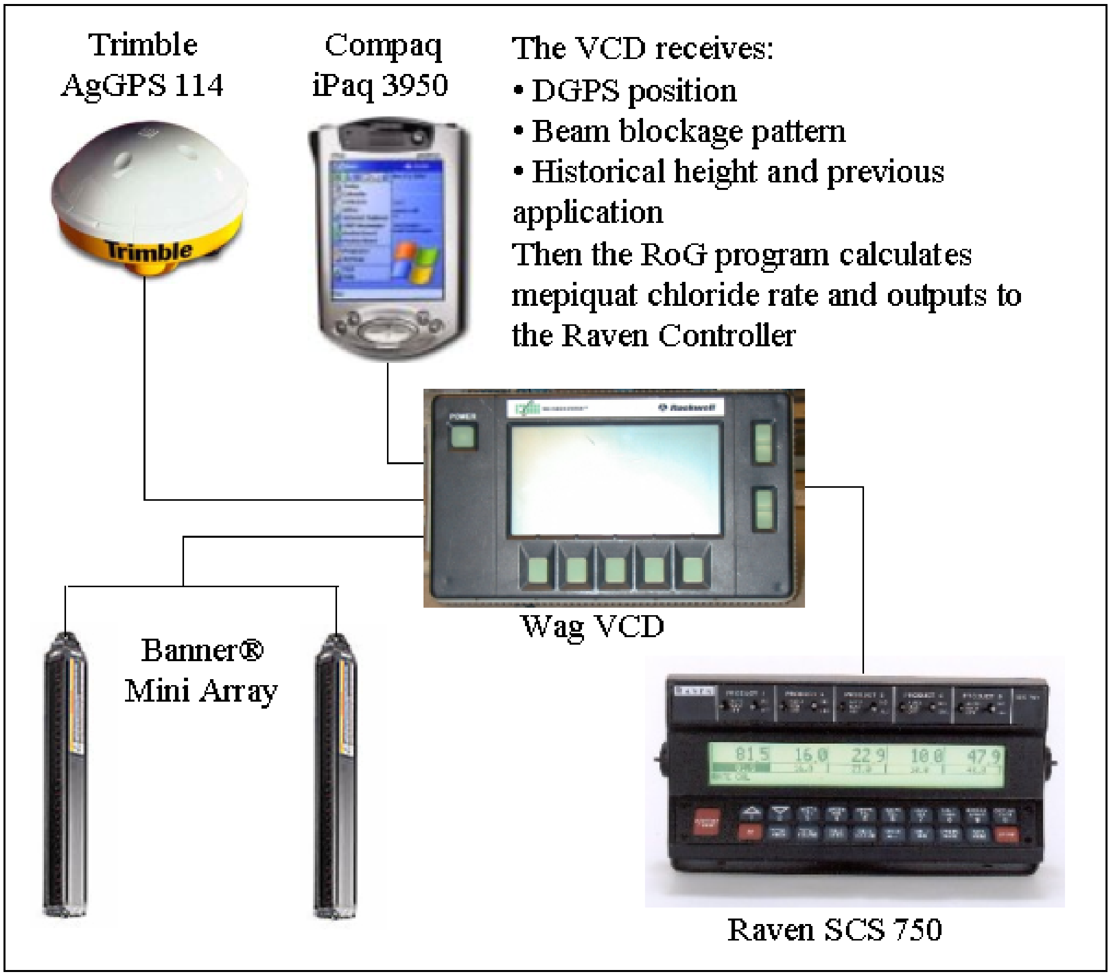
An experiment was designed to test the rate of growth mapping system and variable rate application of mepiquat chloride. The experiment was located at the Texas A&M University IMPACT Center (UTM Zone 14N, 746613 E and 3379857 N) in Burleson County (Brazos River Valley of south-central Texas). An irrigated field with 0.762 m (30 in.) row spacing, planted with DPL-444, was used for the test that consisted of three treatments (control, fixed rate and real-time variable rate) in a randomized block design with five repetitions (blocks) for a total of 15 experimental units (table 10). Cotton was planted on April 5th. Allocation of the treatments within the repetitions was done randomly. Each one of the experimental units consisted of eight adjacent rows and plant heights were measured on the four inner rows.

Table 10. Experimental plot

Experimental Unit	Treatment
1	VR
2	Fixed
3	Control
4	VR
5	Control
6	Fixed
7	Fixed
8	Control
9	VR
10	VR
11	Fixed
12	Control
13	Fixed
14	VR
15	Control

Due to high rainfall preventing field operations, mepiquat chloride was only applied twice (7/6/04 and 7/22/04). Rain and cloudy days did not allow the sprayer to enter the field until plants were close to reaching cutout (NAWF < 5) on 101 DAP. The sprayer was driven over every eight-row plot and mepiquat chloride was applied according to the assigned treatment. On 7/6/04 (92 DAP), the fixed rate of mepiquat chloride was 144 ml/ha (12 oz/ac), while the variable rate ranged from 0 to 288 ml/ha (24 oz/ac). On 7/22/04 (108 DAP), the fixed rate was 132 ml/ha (11 oz/ac), while the variable rate ranged from 0 to 239 ml/ha (20 oz/ac) and historical height for the RoG was interpolated from heights from 7/6/04. The product applied was generic mepiquat chloride at 4.2% active ingredient. Application was done using a John Deere Highboy 6500 sprayer equipped with a Raven SCS-750 for variable rate application, Synchro pulse-width modulated nozzles for flow control and the HMAP system in place for real-time measurement of plant height. The Synchro system pulses the valves on and off, therefore controlling product flow.

Plant height data in each experimental unit was collected in the irrigated field on 7/6, 7/15 and 7/22. The height data was collected using the HMAP system that consisted of a light curtain system that was scanned at 200 Hz and transmitted a histogram of blocked beams. The HMAP program calculated plant height by utilizing the blocked beam histograms. With these histograms, the height was set to be the value half way between the height of 25 and 75% of the maximum number of blocked beams. The positioning was done by a Trimble AgGPS 114 with differential correction provided by Omnistar, with stated sub-meter accuracy. Previous height and application maps (Appendix A) were loaded into the Compaq iPaq 3950 and were used for the rate of growth calculations in the WAG Vision Computer Display (VCD). The height and position was recorded once per second and used by the VCD along with the information provided by the interpolated previous height and application map, to calculate rate of growth and therefore determine an appropriate mepiquat chloride application rate. A schematic of the system is shown in figure 15. A brief description of the equipment used follows in table 11.



The VCD receives:
- DGPS position
- Beam blockage pattern
- Historical height and previous application

Then the RoG program calculates mepiquat chloride rate and outputs to the Raven Controller

Figure 15. Sketch of the HMAP RoG system

The algorithm for the rate of growth calculation was based on the change in height from a previous measurement event. Using the difference in height from the previous measure and the interval in days between measures, the system determined the number of added nodes (assuming 3 days/node). The software then calculated the average internode length (AIL). If this was greater than 3.6 cm (1.4 in) and the added number of nodes was greater than five or the average internode length greater than 3.0 cm (1.2 in) and added number of nodes greater than four (to allow for less than 2 week period between applications), then it would trigger the MEPRT program to calculate the application rate. Growth rates less than the above were to receive a zero rate.

Table 11. Description of the hardware used

Component	Property	Description
Banner® MINI-ARRAY®	Model	BMEL3016A (Emitter) BMRL3016A (Receiver)
	Number of Beams	40
	Beam Spacing	0.75 in
	Output	RS-232 Serial
Compaq iPaq	Model	3950
	Operating System	Windows CE
	Software	AGIS
	Output	RS-232 Serial
Raven Controller	Model	SCS 750
	Input	Rs-232 Serial
	Flow control	Capstan Ag Syst. - Synchro
Trimble® AgGPS®	Model	114
	Accuracy	Sub-meter
	Correction	WAAS/Omnistar
	Update Rate (Max.)	10 Hz
	Output	RS-232 Serial
WAG® VCD	Model	VCD
	Motherboard	Octagon Sys. Corp.® PC-325R
	CPU	80486SLC
	Platform	MS-DOS
	Input	(4) DB9 Serial

The central four rows of each experimental unit were mechanically harvested on 9/20 and separately weighed using a standard weigh wagon. Productivity in kg of lint/ha was then calculated according to gin turnout from the whole experimental area.

An analysis of variance (ANOVA) was conducted to test if any of the treatments had an effect on yield. Another ANOVA was conducted on the average height of every treatment to check if there was any increase in average plant height between mapping dates.

Manual and machine based measurements were done to determine the accuracy and repeatability of the height measurements. Plant height measurements were manually collected along a row on two dates. Manual plant height was averaged over two rows every 0.6 m for 30 m row segments. Machine based measurements were collected automatically every second. Areas of high variability (tall-short, dense-spaced plants) were selected so that the data from HMAP could be compared over a range of conditions. The sprayer with the HMAP system in place was driven at 1.34 m/s (3 mph) and 2.68 m/s (6mph) over the same areas where manual data was collected. The sprayer was driven at both speeds in two directions, east to west and west to east.

Plant height profiles were compared. Data was resampled through a linear trend function between points so that height points were plotted every 2 m, using data from 5 m to 25 m, to eliminate uncertainty at the start and end of the 30 m row segment. Height profiles were matched using markers present in the field that identified the beginning and ending of each row segment replication. Due to recording on a one second interval, it was not possible to identify the markers for one of the dates and results shown are for one day only. Heights were then compared, and correlations established.

RESULTS AND DISCUSSION

The HMAP system has been used for not only estimating plant height maps in the field, but also for determining mepiquat chloride rates according to plant height (HMAP-RT) and rate of growth (HMAP-RoG). Testing the systems is fundamental for the variable rate application of mepiquat chloride. This is done by: comparing height profiles in different dates to check if the plant growth trend is consistent; comparisons of manual and HMAP collected height data, to check if what is recorded follows the trend of manually collected data; and comparing the calculated application rate to the average internode length and effectively applied rate, is necessary to characterize and understand the dynamics of the system. The effect of mepiquat chloride in yield is not the focus of this research, nor was expected due to the late application of the product, but it is compared to check if there was any effect of the variable rate application.

The effect of mepiquat chloride (M.C.) in increasing yield has been studied by many authors, but has not been consistently shown. Particularly given the delay in application dates due to rainfall, the treatments were not expected to have any significant effect in yield or height. The tests were conducted primarily to test the performance of the system. Lack of yield impact was confirmed by the ANOVA, in which yield was not affected by the mepiquat treatment, nor by the replications (table 12).

Table 12. ANOVA on yield for the variable rate mepiquat chloride experiment

Yield	D.F.	Sum of Squares	Mean Square	F-Value	Pr > F
M.C. Treatment	2	12261.6057	6130.8028	0.47	0.6431
Block	4	35261.9047	8815.4762	0.67	0.6302
Error	8	105094.3357	13136.7920		
Corrected Total	14	152617.8460			

A simple plot of plant height in the same area from different dates shows the performance of the system (figure 16). Height has a consistent trend and shows an increase in plant size throughout the different dates. One can see that where there is a peak due to taller plants, that peak repeats throughout the dates. Correlation coefficients between dates were calculated and while the correlation between data from July 6th and July 22nd is 0.92, the data from July 15th correlates to July 6th and July 22nd with 0.96.

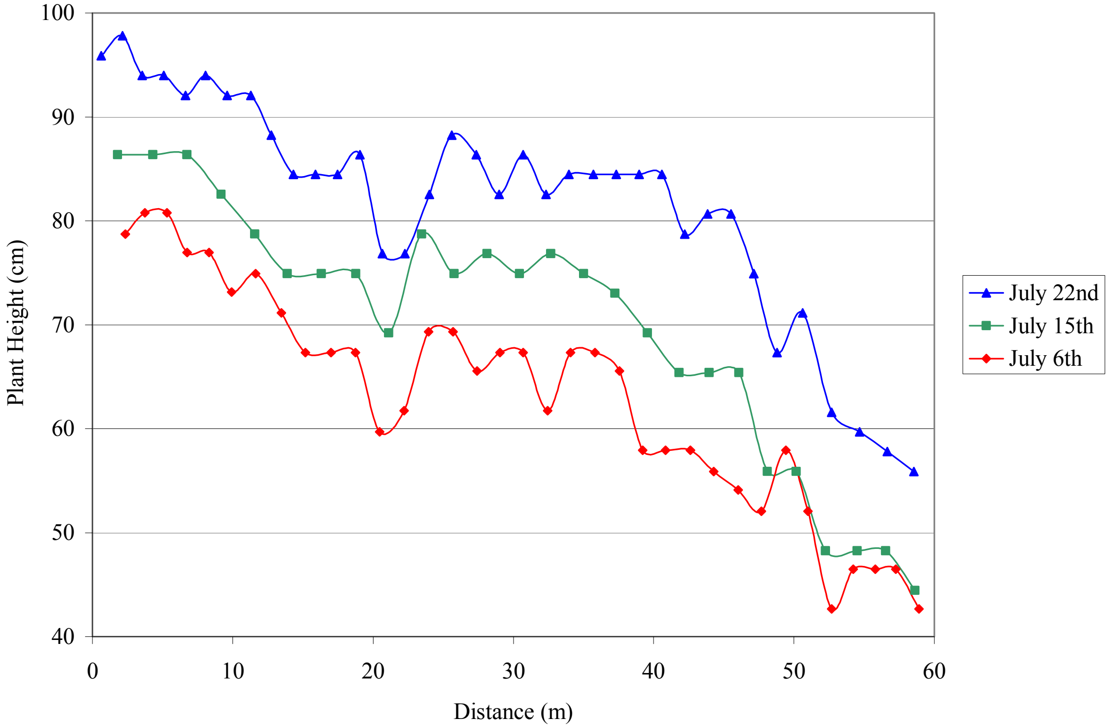


Figure 16. Plant height profile on different dates

Figure 17 is a similar illustration of plant height measurement, but includes some erroneous data points. The system generally performs well, although a few zero height points were recorded when there were plants in the field. These intermittent problems were attributed to anomalies associated with an overflow of the plant height sensor buffer. Another error that can be noticed is that on July 6th there is one data point with a height value greater than 100 cm. This can occur if the driver oversteers during a correction and causes a misalignment on the mini-array that is mounted in the fenders of the front wheels. Since the occurrence is low, it will have minimal effect on the variable rate application system. Hardware and software improvements are needed to eliminate these zero height points and calibration of the mini-array must be done before the season, to ensure alignment. Optimization of the height calculation algorithm and filtering of bad data points are necessary.

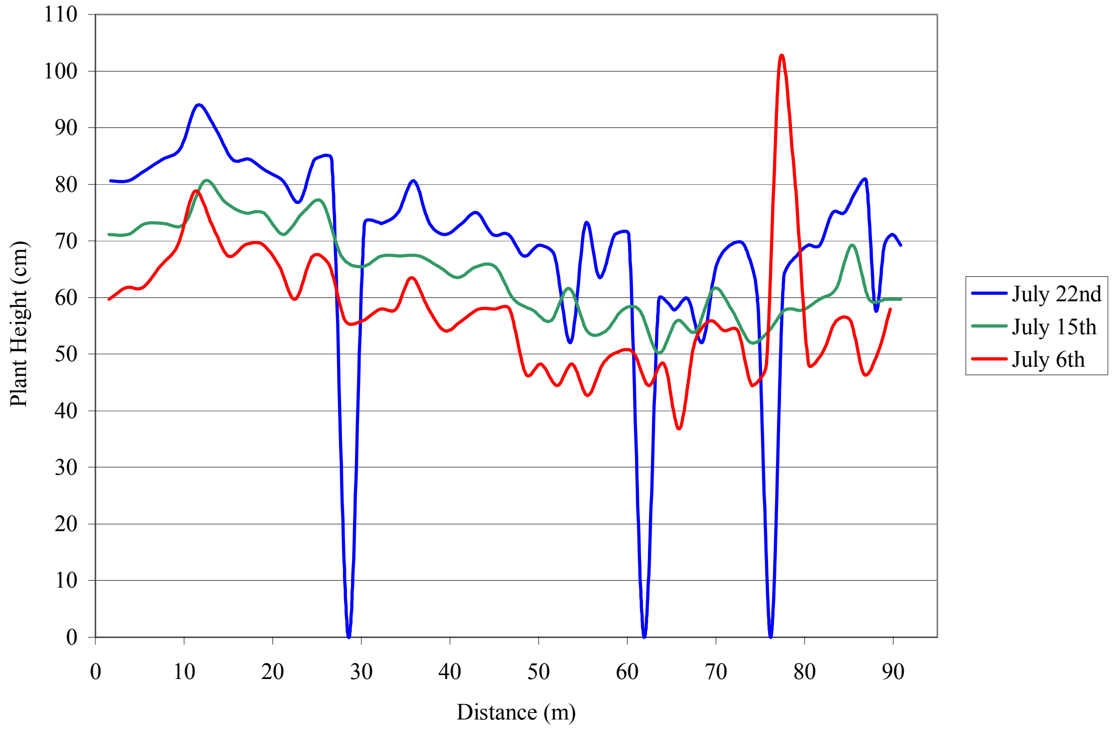


Figure 17. Plant height profile on different dates with some bad data

Mepiquat chloride applications were only done twice due to weather conditions. On the first application (July 6th), no previous height map was available, so rates were based on plant height only in the variable rate treatments. Problems with the Raven controller resulted in the fixed rate treatment varying from the target rate of 144 ml/ha, with the actual rate varying from 120 to 180 ml/ha. On the second application date, the problems were eliminated and the target rate was accurately applied.

A plot of average internode length and calculated rate throughout the sprayer pass for July 22nd is show on figure 18. This data pointed out an error in the system. Originally, application of mepiquat chloride should be done only when the plants had an AIL greater than 3.6 cm (1.4 in), but problems in the software considered the value of 1.4 cm instead of 1.4 in. It can be seen that there is a calculated application rate for when the AIL was greater than 1.4 cm. The variation in the rates, tough is attributed to the rate of growth of the plant and also to the previous application of mepiquat chloride (7/6/2004).

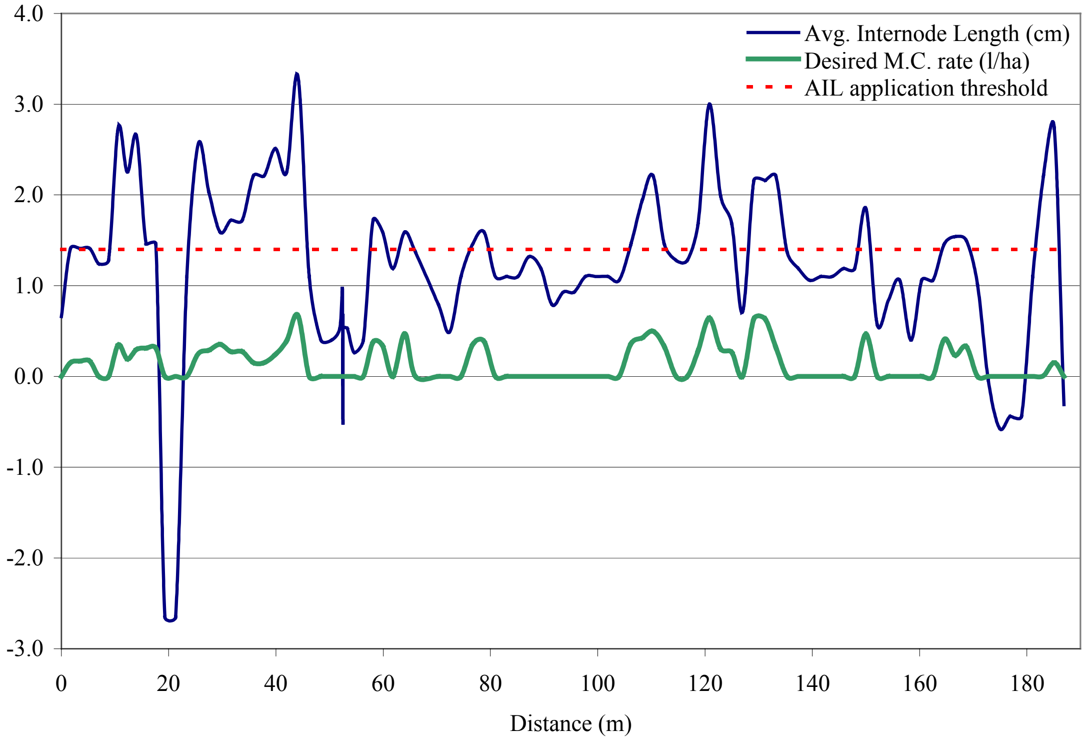


Figure 18. Profile of average internode length and desired mepiquat chloride application rates on July 22nd

Figure 19 illustrates the differences in calculated and applied rate of mepiquat chloride. This difference is caused by the lag of time of when the VCD outputs the rate and the controller effectively applies the rate. Application rate changes were generated for the Raven controller every second. The Raven controller cannot handle such a fast change in application rates. A software modification is needed to better match the dynamic response of the Raven controller with changes in the application rate set point.

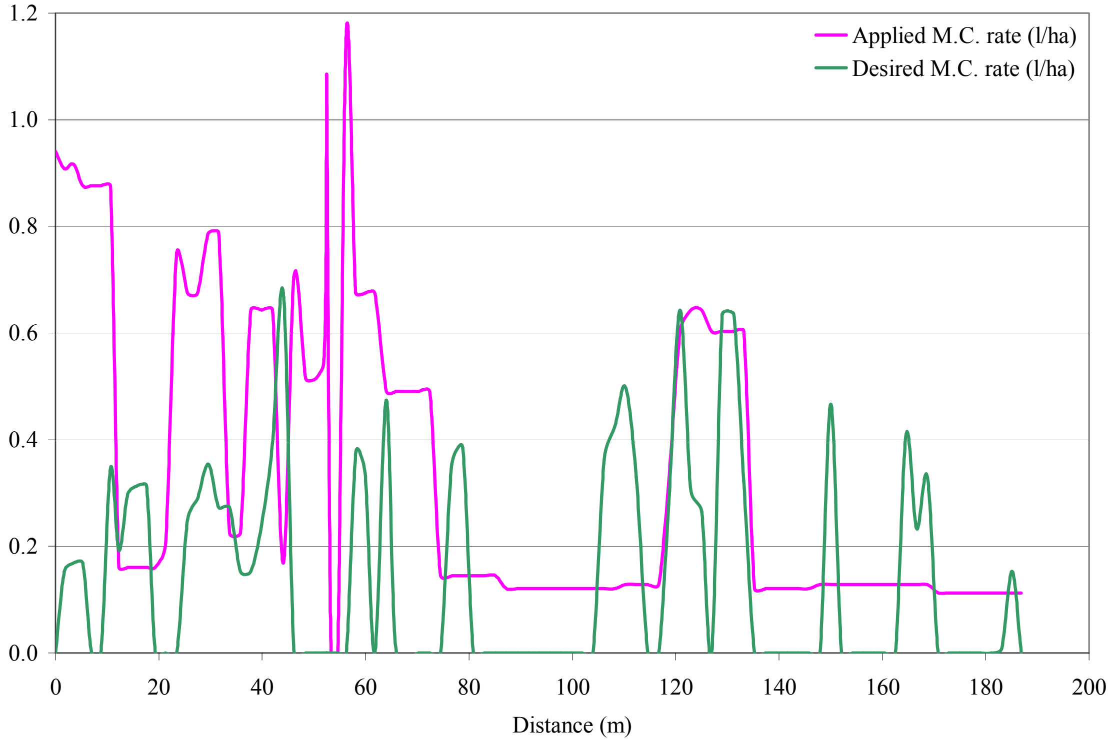


Figure 19. Calculated and applied mepiquat chloride rates

Manual measurements of plant height were collected along with data from the HMAP system driven at two different speeds and on both directions. While the higher speed of travel (2.7m/s) reduces the resolution of data, there is a very good agreement with the data collected at 1.3m/s, as can be seen on table 13.

Table 13. Correlation coefficients from machine based and manual measurements

	1.3m/s WE	1.3m/s EW	2.7m/s WE	2.7m/s EW	Manual
1.3m/s WE	1.00				
1.3m/s EW	0.92	1.00			
2.7m/s WE	0.95	0.92	1.00		
2.7m/s EW	0.95	0.94	0.95	1.00	
Manual	0.88	0.88	0.87	0.91	1.00

A plot of the manual and machine based height measurements are shown on figure 20. It is interesting to note that the data collected by the HMAP system follows very well the trends and differences can be attributed partially to the inherent characteristics of the measurements approaches. While the manual data was collected every 60 cm, and it was an average over two rows, the machine based measurements were made by the light sensors over four rows and computed every second for the section of rows that had been traversed. The different travel speeds would then have a great effect on the resolution of the data. The manual height was a measurement at a specific point, while the machine scanned the light beam array at 200 Hz, and height was calculated from histogram of beam blockage.

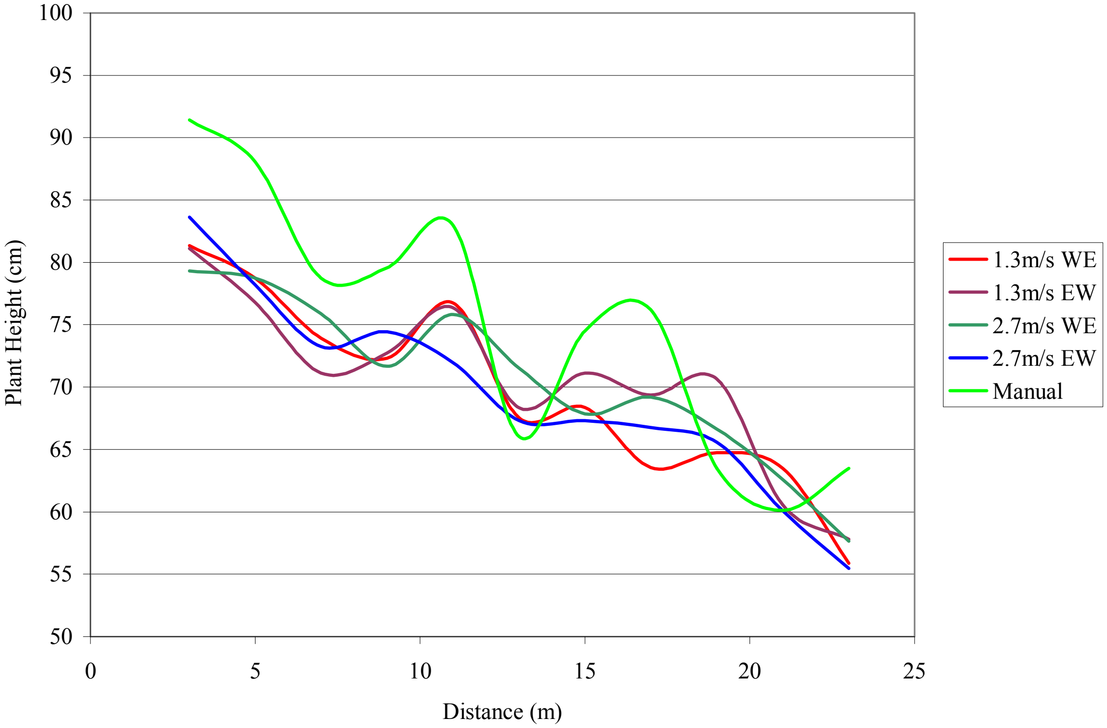


Figure 20. Height profiles of machine based and manual data collected on the same area

The average height of each treatment within a block for each one of the dates was used in an ANOVA to check if there were significant increases in measured height within date (table 14). One can see that there is an effect for date with alpha = 0.01.

Table 14. ANOVA table for average height within date

Source	D.F.	Sum of Squares	Mean Square	F-Value	Pr > F
M.C. Treat	2	23.76	11.88	0.32	0.7261
Date	2	2558.80	1279.40	34.77	<.0001
Block	4	1610.56	402.64	10.94	<.0001
Error	36	1324.72	36.80		
Corrected Total	44	5517.84			

The means were then compared by Tukey's test to determine if there was a significant change in average height between days (table 15).

Table 15. Tukey grouping for average height within date (alpha =0.01)

Tukey Group	Mean (cm)	N	Date
A	74.555	15	July 22nd
B	67.196	15	July15th
C	56.203	15	July 6th

Means with the same letter do not differ

Due to the late application of mepiquat chloride, an effect on height was not expected. The experiment was the initial field test of the HMAP-RoG system, and was intended to identify system performance and limitations. The main problems that could be seen were the delay and change of the calculated and effectively applied rate. The main effect tested would be to check whether the variable rate application of mepiquat resulted in more uniform plants at the end of the season. Unfortunately, due to weather condition, the first time that mepiquat was applied there was no previous height map; therefore the variable rate application was based on plant height. Two weeks later, with the problems with the Raven controller being solved, it was possible to apply a fixed rate and to test the RoG algorithm, by applying a variable rate of mepiquat chloride. Later in the season, though, it was not possible to collect height data with the HMAP system and check if heights were more uniform in the variable rate area.

CONCLUSIONS

The height estimation algorithm works properly and correlation coefficients between manual and HMAP collected data are greater than 0.85.

The RoG algorithm was not functioning properly, and some software changes are necessary to optimize the system.

The variable rate application of mepiquat chloride based on continuously measured rate of growth is viable and promising in its results. Software and hardware changes are necessary so that the applied and calculated application rates are comparable.

Due to the late application of mepiquat chloride it was not possible to determine if there was a significant effect of the variable rate application of mepiquat chloride.

FUTURE RESEARCH

The height estimation algorithm must be optimized through field and lab testing. Another change would be to establish a maximum change in application rate or output a rate change in a longer interval (every 3 seconds, for instance), so that the calculated and applied rates agree.

In the field it is suggested to continue driving the sprayer at both speeds and in both directions, but it is also suggested the use of a different marker in the field so that it is assured that data at least one point is collected on the start and ending mark. It is also suggested to align the light beams with the end of the mark and collect points for a few seconds that will serve as the reference location of start and end of manual data collection. Optimization of the algorithm in the lab should include an analysis of the histogram of beam blockage and a suggestion is to consider the median instead of the average between 25 and 75% of blocked beams.

Collection of a height map around ten days prior to first mepiquat chloride application is also suggested, weather allowing. This will ensure that the variable rate application of mepiquat chloride is done utilizing the HMAP-RoG.

Currently the HMAP system does not account for the difference in location between the GPS unit and the mini-array. Therefore the location assigned to a particular set of plants is actually the location of the GPS unit. It is suggested that the software be changed to correct for this offset.

Due to the increased complexity of the HMAP system it is also suggested that the embedded computer (VCD) is updated, as the current CPU is nearly used to its maximum.

CHAPTER IV

VALIDATION OF THE SOIL LINE TRANSFORMATION TECHNIQUE

INTRODUCTION

Remotely sensed images have proven valuable to farmers who want to reduce production costs and maximize productivity. Through image analysis, one can assess soil conditions, estimate parameters such as leaf area index (LAI), yields and normalized difference vegetation index (NDVI), among others. This information helps in decision-making and optimizing production, through a better comprehension of crop development.

Images taken of the same area on different dates or under different atmospheric conditions are not directly comparable, and have to be normalized in some manner to minimize errors due to differences in the imaging conditions. Currently, the standard for image correction is to convert the images to true reflectance values, so that images taken on different dates or locations could be compared. Unfortunately, obtaining the image correction data is cumbersome for farming conditions. Some authors suggest placing known reflectance surfaces, such as tarps, in the field, when acquiring images. The main disadvantage for doing so is that it is very time consuming and tarp reflectance values also vary with time. Another possible solution would be to use invariant features found in the image (rooftops, roads, etc.). Images would be calibrated based on these features, limiting the method to those images that include invariant features.

One characteristic that is inherent to each soil is the soil line. This concept has been used for years in remote sensing. The soil line is a linear relationship between reflectance of the near-infrared and red bands. By using this well known relationship, the soil line transformation (SLT) technique estimates a regression line from soil points selected in the image and calculates each image's soil line. Images taken on different dates can be matched to a chosen standard (reference image) where relative reflectance is calculated and comparable to true reflectance. This technique is cost-effective and it does not depend on invariant features or reflectance tarps. The main problem of the SLT is that is has not yet been extensively tested under different circumstances, and results have been controversial. The SLT has not yet been compared to true reflectance images.

The overall goal of this research is to improve the value of remote imagery in site-specific crop management and to provide a cost-effective method for improving detection of crop growth changes on a temporal basis.

The *hypothesis* is that transforming a sequence of images to a common soil line will improve the detection of change in vegetation indices.

The main *objective* of this paper is to compare the effectiveness of the SLT technique in improving the detection of changes in vegetation indices over a time series of crop images taken during the entire growing season.

LITERATURE REVIEW

To compare images taken under different atmospheric conditions, one has to calibrate the images. Image calibration can be absolute or relative (Jensen, 2005). Absolute image calibration can be done when true reflectance data is acquired along with the image and the digital numbers transformed to true reflectance values. Relative calibration utilizes features within the images to calibrate them. Various methods have been used to compare multi-temporal images. Schott et al. (1988) tried to normalize images from the Landsat system based on the statistical invariance of man-made elements in the scene (e.g. concrete, roofs). They achieved satisfactory results but with the limitation that every image would have to have some urbanization in order to select the pseudo invariant features. Furby and Campbell (2001) analyzed over 100 Landsat images and used a robust regression based on a large quantity of invariant targets to do so. Images had to have a large enough number of invariant targets and yielded greater results when the image was cloud free and had a clear atmosphere.

Hall et al. (1991) evaluated a technique that also considered reflectance stable elements. He used the optical depth and sensor calibration for the reference image to be able to convert digital numbers (DN) to absolute surface reflectance. Huete et al. (1992) developed a method to normalize red and near infrared reflectance using the soil-adjusted vegetation index (SAVI). This index was less sensitive to the variations in image-taking conditions, since it was a soil-adjusted index. It proved to be effective under the specific circumstances to which the study was conducted.

Moran et al. (2001b) proposed a refined empirical line (REL) approach in getting the reflectance values from satellite imagery. One approach in converting DN to true reflectance is to measure atmospheric conditions while the image is being taken and then convert radiance measurements to surface reflectance. Moran et al. (2001a) tried to calibrate the images from the soil with the use of reflectance tarps. They tested different tarps with different reflectance factors and with different ages and dirtiness. Due to dirtiness, tarp reflectance could range more than 50% if compared to the factory standard, but once tarps were kept clean, errors in reflectance values were minimized. The limitation of tarps as a calibration source was associated to the difficulty of installing heavy and big tarps in the field.

The method adopted in this paper was proposed by Fox et al. (2003). The soil line technique (SLT) is derived from the widely used and known concept of soil lines. This is a relationship between the near infrared (NIR) and red reflectance of bare soil (Galvão and Vitorello, 1998). While it is not possible to determine a global soil line that will cover all the differences in soil conditions, such as soil type, roughness moisture content and others (Fox et al., 2004), each soil will have its characteristic line (Baret et al., 1993).

Within an aerial image, pixel values will contain not only bare soil pixels, but also crops, and any other feature that resides in the image. To acquire a significant soil line, one must correctly identify the bare soil pixels. Figure 21 shows that since leaves are more photosynthetically active, the NIR reflectance is increased while the red reflectance is lower. Therefore the pixel value will vary with the age of the crop.

Initially the NIR reflectance is low, increases to a maximum when there is maximum leaf area canopy and decreasing again when harvest approaches. The lower points in the dataset would represent the soil line, where there is a minimum NIR value for each red value.

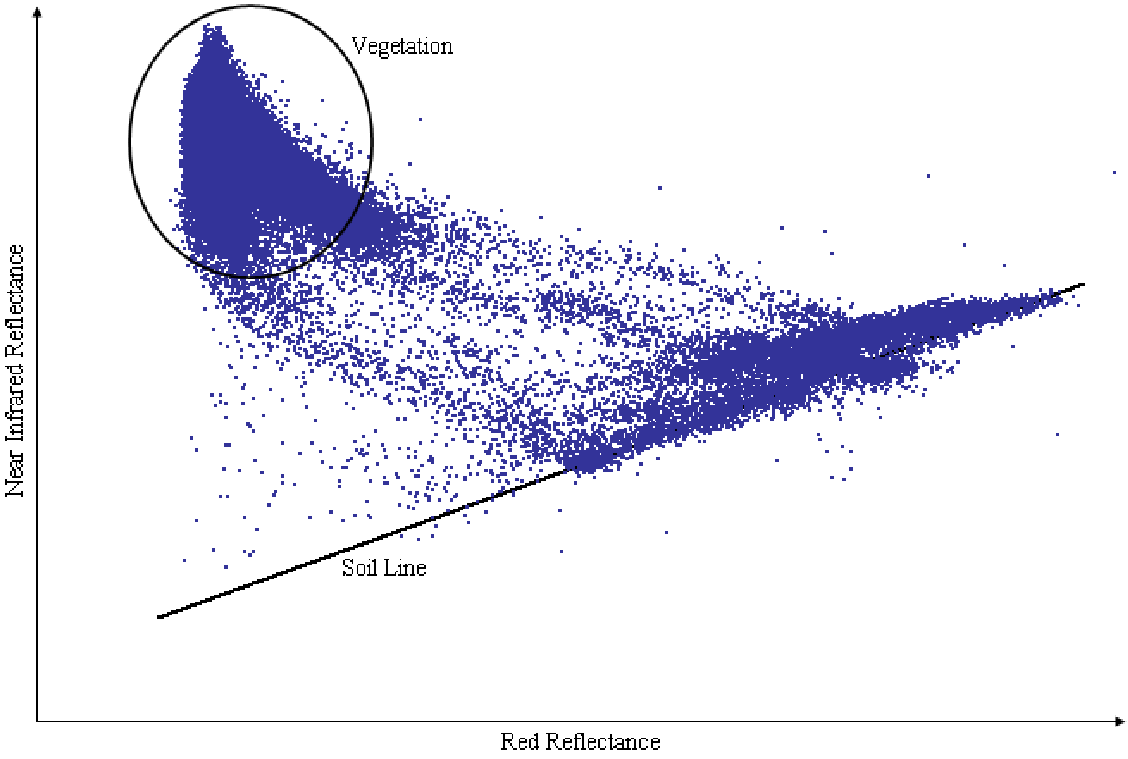


Figure 21. Distribution of reflectance values in an image in the red and NIR regions of the electromagnetic spectrum

Two programs written in FORTRAN and a script written in Avenue compose the SLT technique (Fox, 2000). The script is used to output ASCII files containing pixel values, so that the other programs can use it. The soil line extraction program extracts the soil line from the images through regression of the lower points in the dataset. For each red value, the program searches for the minimum NIR values and uses that to calculate the soil line. The soil line extraction program will output soil line parameters (intercept and slope) for each one of the images. The soil line parameters are then read by the transformation program, which will match each image's soil line to the reference. It will do that by identifying pixels that are either on or close to the soil line of the reference image and the image to be corrected. The transformation program uses the reflectance values of the pixels that fall within a certain distance of the soil line to estimate regression parameters for the red and NIR bands of the image to be corrected. The program then outputs the parameters in a text file. Individual bands must then be corrected and vegetation indices can be compared.

As compared to the method proposed by Schott et al. (1988), manual labor is also minimized in the SLT, since both methods are automated. The SLT, as opposed to most of the available methods, does not depend on: 1) reflectance data acquired during the sensor pass (Huete et al. 1992; Hall et al. 1991; Guyot and Gu 1994); 2) manual installation of reflectance tarps in the field prior to imaging (Moran, 2001a); or 3) manual selection of invariant features (Hall et al. 1991; Guyot and Gu 1994; Furby and Campbell 2001; Moran et al. 2001b). Hence, there is sufficient reason to test the effectiveness of the SLT as compared to true reflectance, as it would result in an effective method of multi-temporal image comparison.

The SLT technique has been compared to the histogram matching technique and was proven to be statistically superior (Fox et al. 2003). For two fields over two growing seasons, it resulted in at least 87% of pixels demonstrating expected growth patterns between images. However, the SLT normalization technique was not compared to true reflectance images or the measured change in biomass. To be considered a robust method, the SLT must be tested further and compared to true reflectance. The potential benefits of the SLT are:

- Minimized imaging costs (not having to acquire reflectance parameters);
- Optimized image processing time (due to automation);
- Improved measures of vegetative indices (over raw Images);
- Improved comparison in a time series of images; and
- Reduced bias (due to human parameter extraction).

MATERIAL AND METHODS

IMAGE PREPROCESSING

The images used in this study were aerial photographs provided by USDA-ARS, Shafter research and extension center in Shafter, CA. Images were taken using three different 12-bit Dalsa® cameras, one for each band (Green, Red and NIR).

There were a total of 11 images for the 1999 crop year. The images had a spatial resolution of 0.7 m and covered three cotton fields and some surrounding areas containing roads, bare soil, other crops and some water bodies. The cotton variety was Maxxa, and planting date was on 5/4/99, while emergence was on 5/10/99, and the area containing cotton was selected for further analysis. The first image was taken on March 3rd and the last one on August 31st covering the whole crop cycle. Of the eleven images provided, ten of them had reflectance panels present, and these were used so that true reflectance could be assessed consistently throughout the image set. The first image considered (6/1/99) was not a bare soil image, since cotton had emerged 20 days earlier, but the plants were small. Table 16 shows the imaging dates of the ten images containing reflectance panels that were used.

Table 16. Imaging dates

Name	Imaging date:
Date 1	(6/1/1999)
Date 2	(6/23/1999)
Date 3	(7/13/1999)
Date 4	(7/14/1999)
Date 5	(7/15/1999)
Date 6	(7/20/1999)
Date 7	(7/28/1999)
Date 8	(8/10/1999)
Date 9	(8/20/1999)
Date 10	(8/31/1999)

The images were provided by USDA-ARS in two forms, as raw images, only containing digital numbers (DN), and as true reflectance images. USDA-ARS personnel did the image conversion from digital numbers to true reflectance. This was done based on three reflectance tarps (white, gray and black) located within the image. Tarp reflectance was measured on the date of image acquisition. A linear transformation from DN to true reflectance was done in RSI ENVI® 4.0 software by USDA-ARS.

To be able to extract vegetation indices from the SLT normalized images, the following steps were completed (Appendix B):

1. Image geo-referencing;
2. Crop image to a common extent;
3. Import images to ArcView®;
4. Convert images to GRID in ArcView®;

5. Run ArcView® script, to output ASCII files;
6. Run the soil line extraction program;
7. Run transformation program;
8. Apply transformation parameters; and
9. Calculate NDVI.

A geo-referenced image was provided and used for geo-referencing of all other images. The image taken on 7/15/1999 was geo-referenced to ground control points (RMS < 1 pixel) from the provided geo-referenced image. All other images were co-registered to the 7/15/1999 image with RMS < 0.42 pixels, as can be seen on table 17. For the geo-referencing, images had to be warped and that was done in RSI ENVI 4.0®, utilizing the nearest neighbor technique.

Table 17. Geo-referencing statistics

Imaging date:	RMS (pixel)
(6/1/1999)	0.238832
(6/23/1999)	0.219122
(7/13/1999)	0.397854
(7/14/1999)	0.202324
(7/15/1999)	0.971313 *
(7/20/1999)	0.413454
(7/28/1999)	0.276538
(8/10/1999)	0.218072
(8/20/1999)	0.137437
(8/31/1999)	0.272566

* - indicates the image geo-referenced to ground control points.

Each image in the set of ten images had a slightly different coverage area of the scene. For the SLT normalization to work properly the images had to cover the same area. An area common to all images was selected and images were then cropped to the common extent, and then resized.

Once images were geo-referenced and resized, they were converted to band interleaved by line (BIL) format in RSI ENVI 4.0®. ArcView® was used to open the BIL images and they were converted to grids.

The grids were then converted by the ArcView® script into ASCII files that could be used by the soil line extraction program. The script was initially set to process sets of four images and was modified to process all ten images at once.

The soil line extraction program, written in FORTRAN, was also set to process four images at a time and was set to handle 8-bit images. The program was then modified to process ten images and deal with the 12-bit images. The soil line extraction program calculated the soil line by regression of the lower points in the dataset. The program searched for the minimum NIR value for each red value and assumed that that point falls on the soil line, and uses this for estimating each image's soil line. The program then outputs parameters for the soil line of each of the images stored as an ASCII file.

The transformation program searches for points that fall on or close to the soil line of the reference and image to be corrected, and with those data it does a regression to match the soil lines and generates correction parameters. To be considered to be on the soil line or close, the program calculates the minimum Euclidean distance (hereafter referred to as "C") of the point to the soil line, if the distance is smaller than the "C" value (set in the FORTRAN program), the point will be considered for the second regression. The program generated slope and intercept transformation values, both for red and NIR for each of the images.

The parameters were then used to transform the images by using the band math calculator in ENVI 4.1®. Once images were transformed, NDVI was calculated using equation 1:

$$NDVI = \frac{(NIR - red)}{(NIR + red)} \quad (1)$$

NDVI's from digital numbers, true reflectance and the SLT transformed images were then compared.

Once the NDVI images were generated, it was noticed that the image registration was not perfect, and so images were re-sampled by the "pixel aggregate" method, in RSI ENVI® 4.1. Each pixel value was calculated by the average of the 8 pixels around it, changing the pixel resolution from 0.7 m to 2.1 m. Therefore, a more representative value of the pixel was used for the comparisons.

TESTING THE SOIL LINE TRANSFORMATION TECHNIQUE

The SLT technique was tested twice: with the common areas of the entire images and with a subset that contained an area of interest composed of a single cotton field and surrounding bare soil pixels.

WHOLE

On the first approach (hereafter referred to as WHOLE), two different images were used as reference images. The transformation program, with the "C" of 20, was used to generate the slopes and intercepts for each one of the bands of each one of the images.

In the WHOLE dataset there were NDVI's calculated from: raw reflectance (DN), true reflectance (TR), SLT with 06/01/1999 as the reference and SLT with 08/31/1999 as the reference image. The soil line calculated by the soil line program was extracted from the full extent of figure 22. Comparisons of NDVI were then done within the evaluation area (selected area in figure 22) containing only cotton.

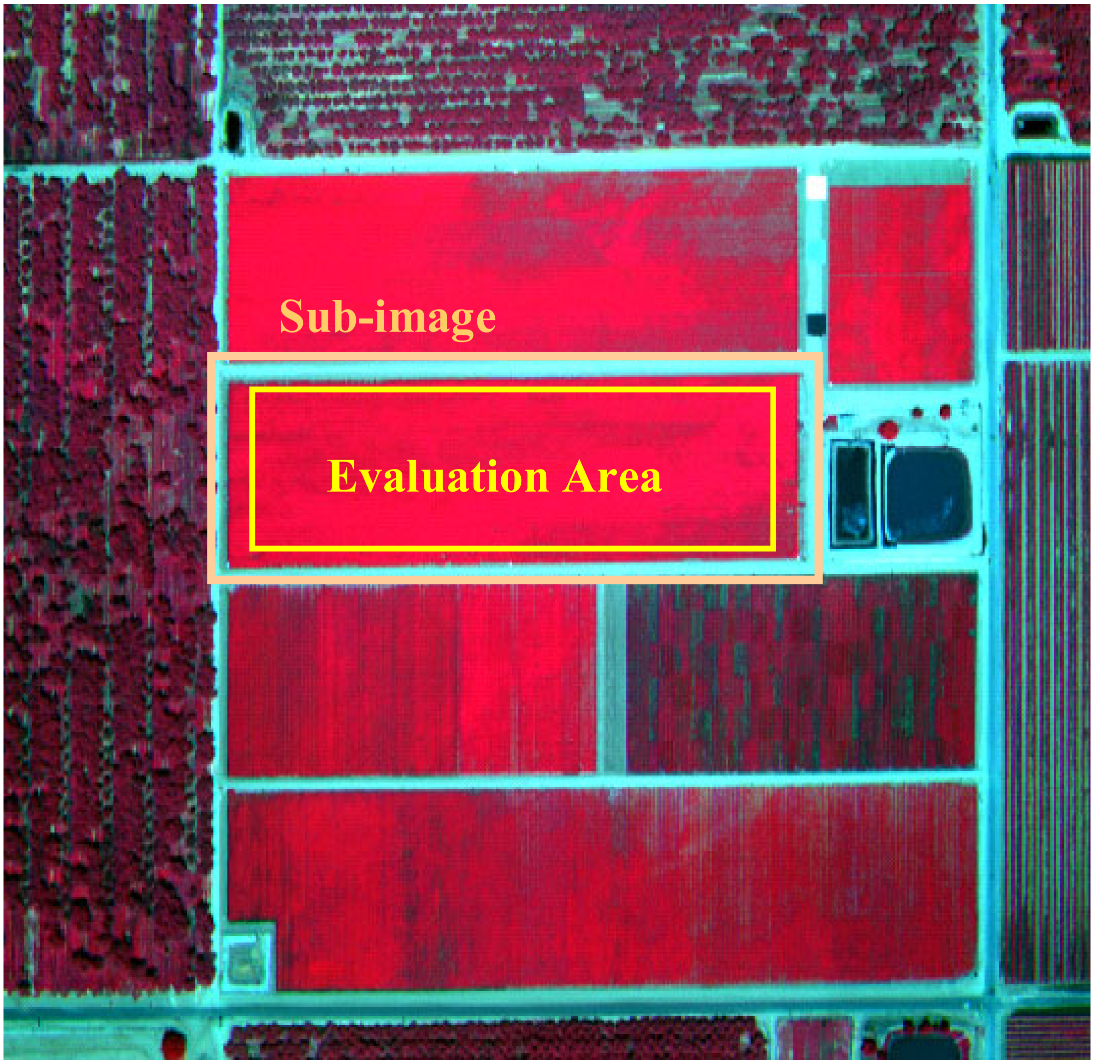


Figure 22. Selected region of interest from whole image

Sub-image

There were some differences in the processing done on the second approach (hereafter referred to as sub-image). The ArcView® script no longer was used to generate the ASCII files of pixel values. RSI ENVI 4.1® was used for that purpose. The ASCII files generated by RSI ENVI 4.1® had to be somewhat modified to be used by the soil line extraction program. A line of data containing "NODATA_value -9999" had to be inserted. Once the ASCII files were modified, the soil line program was used to extract the soil lines from the sub-image. Since the extracted soil lines were not very representative, soil lines were also extracted manually for each image from the plot of the red and NIR (figure 23). The transformation program was then used to extract the correction parameters (intercept and slope) for the red and NIR bands for each of the images, and the "C" values utilized in the transformation program were variable (10 and 20), to maximize the significance of the regression.

The sub-image dataset had NDVI's calculated from raw reflectance, true reflectance and SLT with 06/01/1999 as the reference. Analysis was conducted on a subset of the data containing only cotton, since the objective was to track change in NDVI on the vegetation.

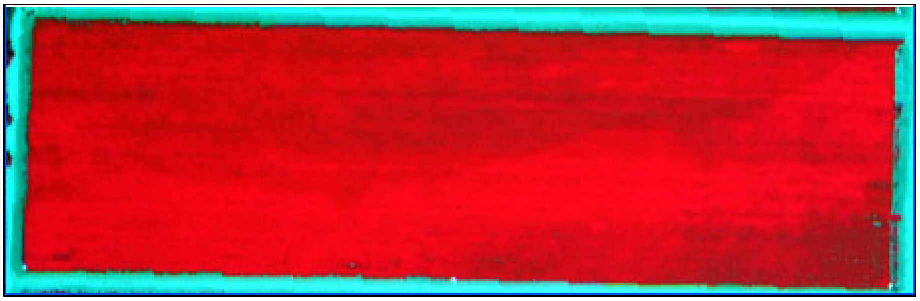


Figure 23. Area used for the sub-image dataset

Transformation Comparisons

The goal was to check how well the change in vegetation indices calculated from normalized images would compare with the change when calculated using true reflectance images. Vegetation indices, in this case NDVI, extracted from both approaches (WHOLE and AOI) were investigated and compared.

RESULTS

WHOLE

For the WHOLE dataset, the soil line extraction program calculated soil lines automatically. Intercepts and slopes can be seen on table 18.

Table 18. Soil line parameters from the WHOLE dataset

Imaging date	Slope (m)	Intercept (b)
6/1/1999	0.4944	211.1493
6/23/1999	0.9177	270.928
7/13/1999	0.8114	437.1702
7/14/1999	0.6484	362.7439
7/15/1999	0.6583	326.4242
7/20/1999	0.668	333.6465
7/28/1999	0.7362	314.215
8/10/1999	0.6346	306.1745
8/20/1999	0.6519	341.4775
8/31/1999	0.6943	235.176

Figure 24 shows an example of the calculated soil line from the extraction program. It can be seen that a few low values on the right side of the figure are influencing the soil line. While the intercept seems to be appropriate, the slope of the line is too small.

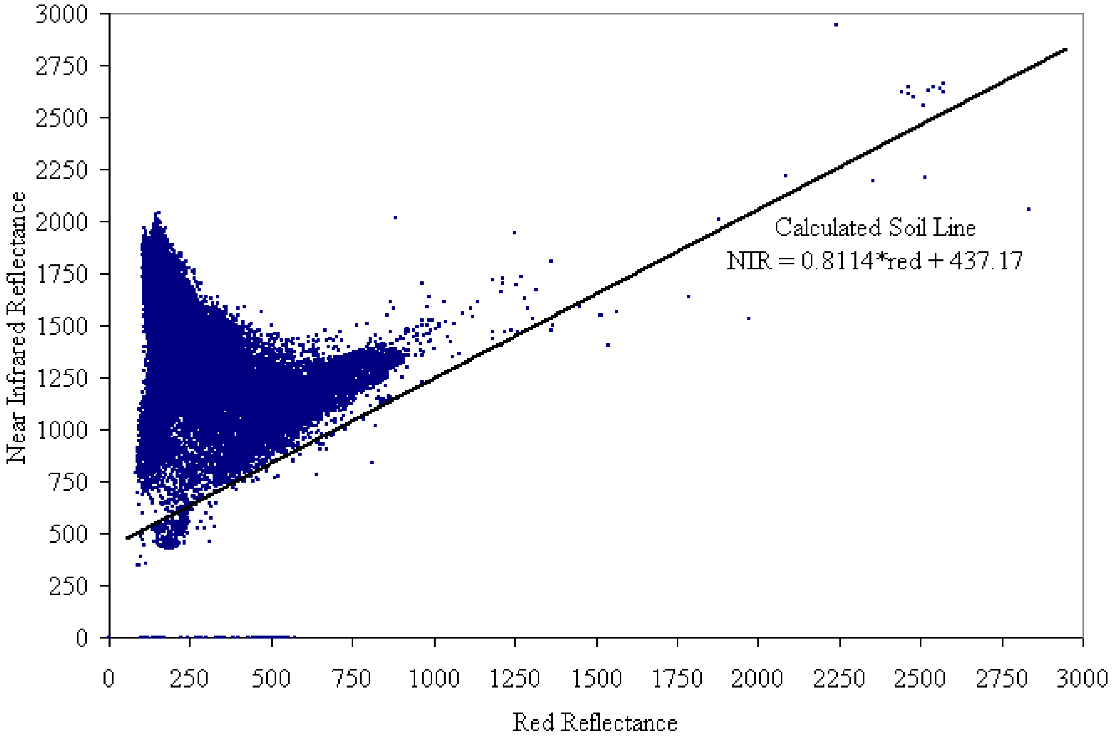


Figure 24. Calculated soil line from the WHOLE dataset on 7/13/1999

The transformation program was run twice: one utilizing 6/1/1999 as the reference image, and again utilizing 8/31/1999 as the reference image. Calculated soil lines were visually compared to the pattern of red/NIR points, and were found to be poor estimates for most images. Even knowing that the soil lines were not the best, transformation parameters were extracted by the transformation program. The program was run with the "C" value of 20. Intercepts and slopes for both cases are shown on table 19 and were used to transform the images.

Table 19. Correction parameters for the WHOLE dataset

Image dates	Band	8/31/1999		6/1/1999	
		Slope (m)	Intercept (b)	Slope (m)	Intercept (b)
6/1/1999	NIR	1.238	-83.030	Reference	Reference
6/1/1999	Red	0.886	-107.619	Reference	Reference
6/23/1999	NIR	0.822	153.683	0.696	135.161
6/23/1999	Red	1.092	189.848	1.283	261.825
7/13/1999	NIR	1.055	-146.396	0.655	126.338
7/13/1999	Red	1.222	123.037	1.114	397.096
7/14/1999	NIR	1.005	-1.802	0.779	125.664
7/14/1999	Red	0.943	171.394	1.022	400.565
7/15/1999	NIR	0.359	392.875	0.652	96.109
7/15/1999	Red	0.337	392.236	0.863	227.131
7/20/1999	NIR	0.878	11.485	0.602	183.508
7/20/1999	Red	0.851	84.709	0.817	362.853
7/28/1999	NIR	0.881	-19.276	0.612	217.508
7/28/1999	Red	0.937	23.787	0.926	388.449
8/10/1999	NIR	1.115	-68.634	0.537	315.717
8/10/1999	Red	1.023	56.470	0.624	555.173
8/20/1999	NIR	1.060	-19.542	0.677	256.827
8/20/1999	Red	0.991	162.996	0.910	541.747
8/31/1999	NIR	Reference	Reference	0.805	74.621
8/31/1999	Red	Reference	Reference	1.132	124.195

Once the images were transformed, NDVI's were then calculated from the evaluation area. A histogram of the distribution of NDVI values for each one of the methods on 6/23/1999 is shown on figure 25. One can see that the shape of the histogram is similar for all four methods, but that the SLT transformed images have a lower mean. NDVI's extracted from the digital numbers are much closer to the true reflectance NDVI's. The transformed image distributions were expected to fall between the raw and true reflectance distributions.

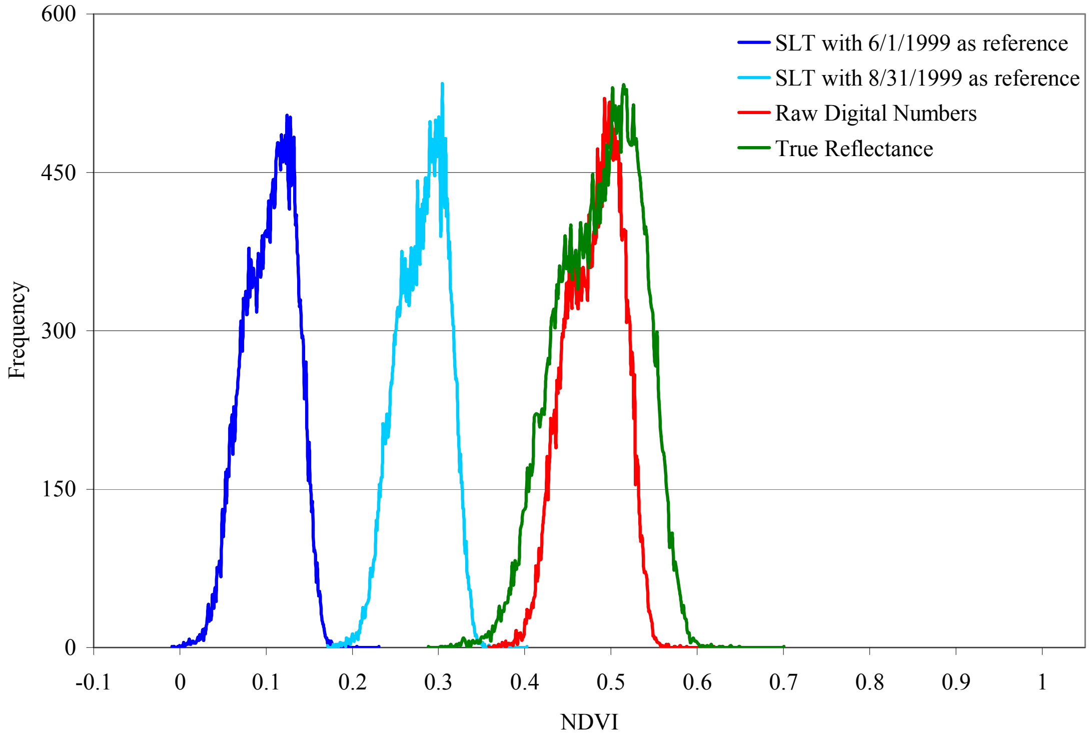


Figure 25. Histogram of NDVI distribution on 6/23/1999 from the WHOLE dataset

The pattern of histogram distribution was similar for all other image dates, with SLT transformed images having lower values than the NDVI's extracted from raw data.

Figure 26 shows the temporal trend of the NDVI means of the four methods for the ten different dates. It can be seen that the NDVI's calculated from the raw images have means that are closer to the true reflectance values.

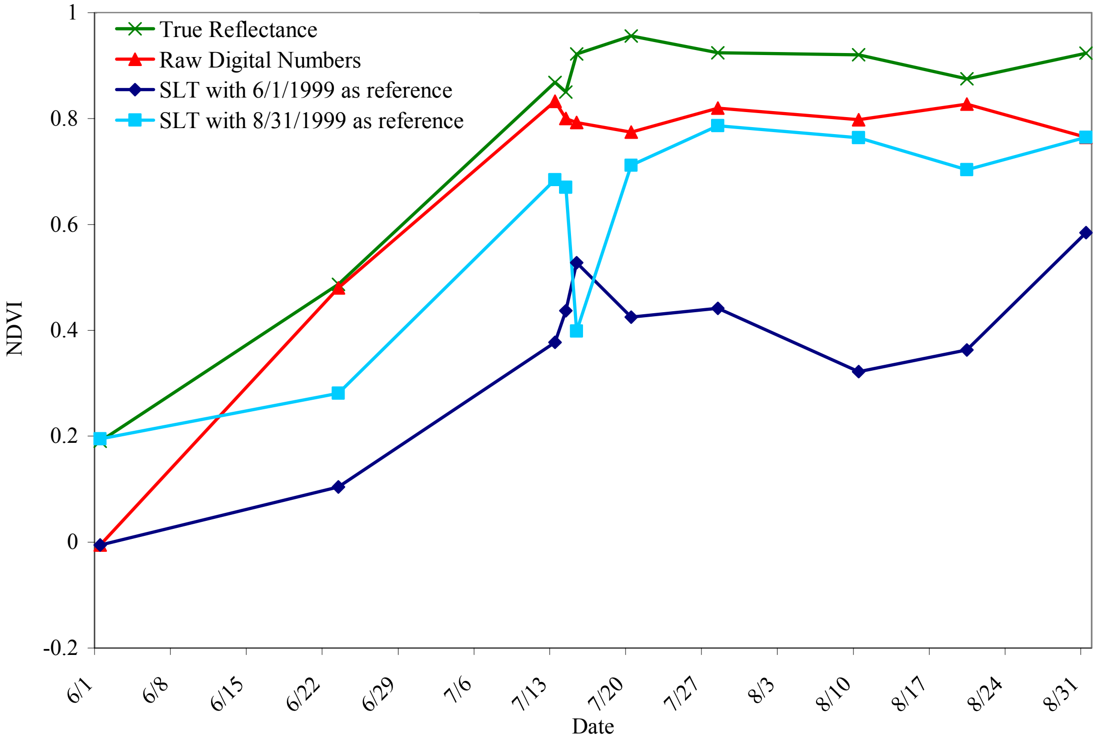


Figure 26. Temporal trends of the NDVI's for all different methods

Since the soil line is supposed to be a more stable feature in each field, the results shown from the WHOLE dataset do not support the validity of the SLT technique in improving detection of vegetation indices if compared to the raw NDVI's. The poor results from this approach are mainly attributed to the soil line extraction program, which did not extract accurate soil lines. Soil lines calculated automatically were not representative of the true soil lines, and an example is seen on the plot of the red and NIR bands (figure 24). Features such as the water bodies and reflectance panels present in the field affected the soil line extraction program that was searching for the minimum NIR values for every red value.

SUB-IMAGE

To minimize the influence of features that were not of interest, the second approach was conducted. Automatic soil lines were extracted from a subset of the whole image only containing bare soil and cotton pixels. Table 20 shows the defined soil line parameters for each one of the images, as calculated by the soil line program. It is known that the soil line should have a positive slope, but, as one can see, table 20 shows some negative slopes and very low r^2 for the regression. This occurred because the soil line program used the minimum NIR value for every red value to calculate the regression. From 7/14 to 8/20, there was a lot of vegetation in the field, and the low NIR values for every red value did not necessarily fall on the soil line. The absence of an intercept also is an indication that something is not functioning properly.

Table 20. Regression parameters from the soil line program

Imaging date	Slope (m)	Intercept (b)	Regression r^2
6/1/1999	0.3751	470.9044	0.8344116
6/23/1999	0.518	802.5732	0.7871525
7/13/1999	0.4764	829.0945	0.6309474
7/14/1999	0.0011	*******	2.20E-03
7/15/1999	0.0477	*******	0.100772
7/20/1999	-0.066	*******	-0.1210462
7/28/1999	0.1126	*******	0.2432049
8/10/1999	-0.0514	*******	-0.1064313
8/20/1999	0.0143	*******	2.59E-02
8/31/1999	0.1787	892.7892	1.33E+07

The soil lines from the extraction program were plotted and investigated. This confirmed the theory that the soil line calculated automatically was not falling on the soil line shown by the plot of the red and NIR values. To continue evaluation of the SLT technique, soil lines were drawn manually. The parameters for these equations can be seen on table 21. All the slopes are positive and much higher than the ones suggested by the soil line extraction program and that the intercepts calculated manually have lower values. A plot of the red and NIR values, with the soil line from the program and the manual is shown on figure 27. One can see that neither the intercepts nor slopes agree.

Table 21. Regression parameters from the manually extracted soil lines

Imaging date	Slope (m)	Intercept (b)
6/1/1999	0.5941	258.91
6/23/1999	0.9231	546.92
7/13/1999	1.0979	450.00
7/14/1999	0.5633	652.16
7/15/1999	0.8242	435.76
7/20/1999	0.8500	430.00
7/28/1999	0.7089	652.85
8/10/1999	0.6024	559.64
8/20/1999	0.6369	564.01
8/31/1999	0.5130	571.50

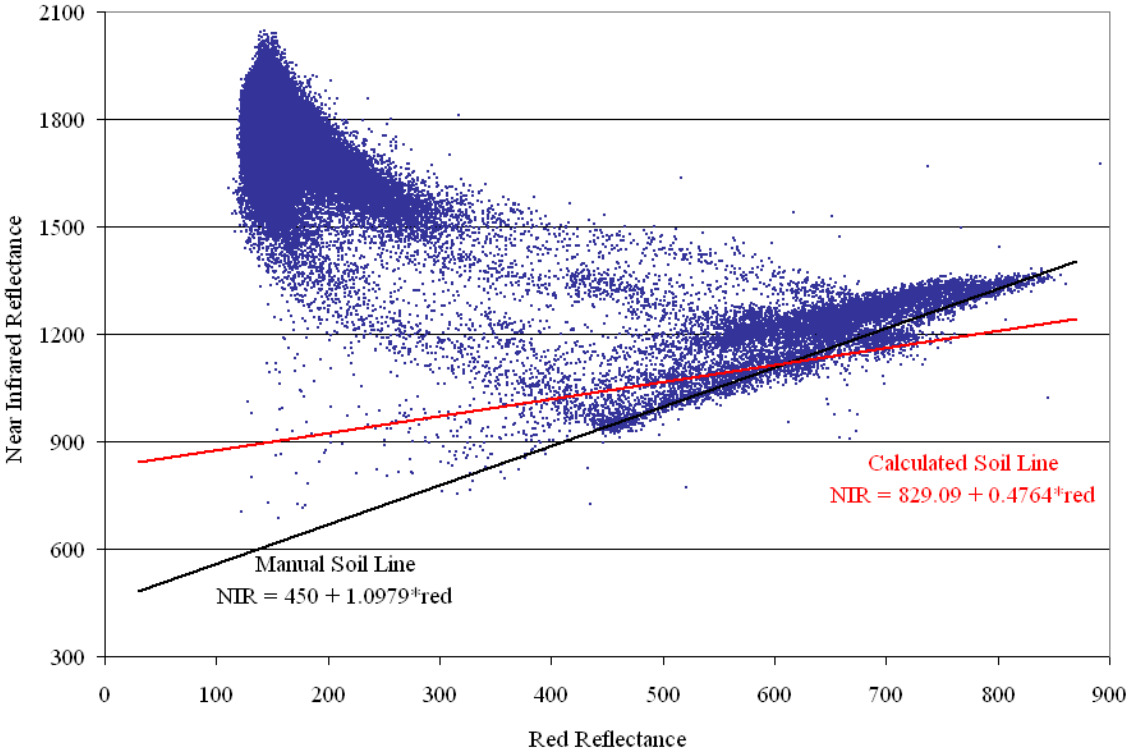


Figure 27. Calculated and manual soil lines from the sub-image dataset on 7/13/1999

The soil line extraction program searches for the minimum NIR value for every red value. On a 12-bit image, both the red and NIR values vary from 0 to 4096. The program will search for a minimum NIR for all 4096 values of red, regardless of whether the pixel falls on the soil line or is from a vegetation portion of the image. The inclusion of all these points affects the slope and intercept of the soil line, as seen on figure 27. In some cases the calculated soil line had a very small or even negative slope (table 22), which also confirms the inappropriateness of the soil line extracted automatically.

Table 22. Correction parameters for the sub-image dataset

Imaging	Transformation	Red		NIR	
date	origin	Slope (m)	Intercept (b)	Slope (m)	Intercept (b)
6/1/1999	Reference				
6/23/1999	C10	1.5377	-79.0774	0.9906	-330.6279
7/13/1999	C10	1.5702	52.3619	0.8485	-90.7286
7/14/1999	C10	1.3434	-96.0881	1.3966	-700.4848
7/15/1999	C10	1.1687	-87.0314	0.8488	-167.6533
7/20/1999	C20	0.9859	-207.9284	0.4860	173.2248
7/28/1999	C10	1.2961	-189.5335	1.0853	-562.5080
8/10/1999	C20	1.1243	-241.3067	0.7971	-95.3889
8/20/1999	C20	1.4525	-152.8593	1.3368	-576.4478
8/31/1999	C10	0.7908	249.6792	0.9114	-111.4303

Since the manually selected soil lines were more appropriate, the transformation program was run on the parameters extracted manually. The program was utilized with the "C" values of 10 and 20. The correction parameters, for C equal 10 or 20 were selected to improve performance of the transformation and can be seen on table 22. This was done by comparing the regression values from plotting the reference and corrected values for the red and NIR bands. The parameter (C equal 10 or 20) selected was the one where the r^2 was highest.

Once images were transformed, NDVI's were calculated. Histograms of data distribution were plotted to check the distribution of NDVI values for the different methods. The histograms in this case consist of data from the entire sub-image dataset, with bare soil pixels and cotton area. Figure 28 shows that even the SLT transformation yielded a lower mean and the area where the vegetation would be (NDVI > 0.3) are more spread than the true reflectance and raw NDVI's.

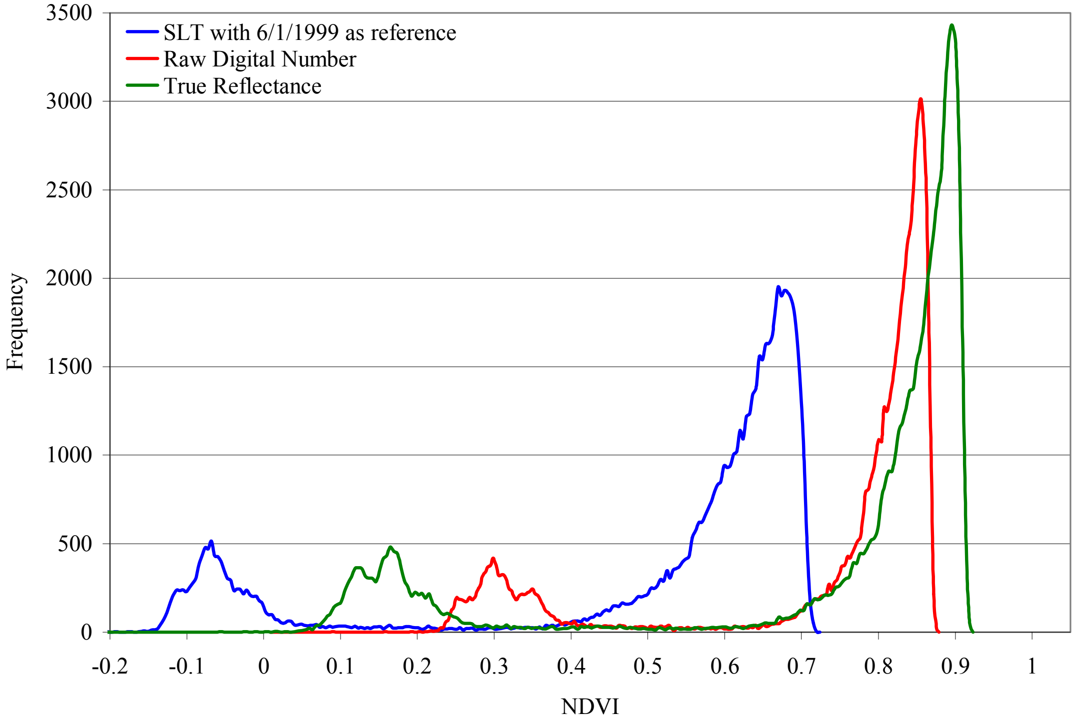


Figure 28. Histogram of NDVI distribution on 6/23/1999 from the sub-image dataset

This pattern though is not consistent however. In other images, the SLT outperforms the raw NDVI's, as seen on figure 29. The distribution of the raw and SLT NDVI's are very similar, but the SLT histogram is stretched further and the mean is closer to the true reflectance.

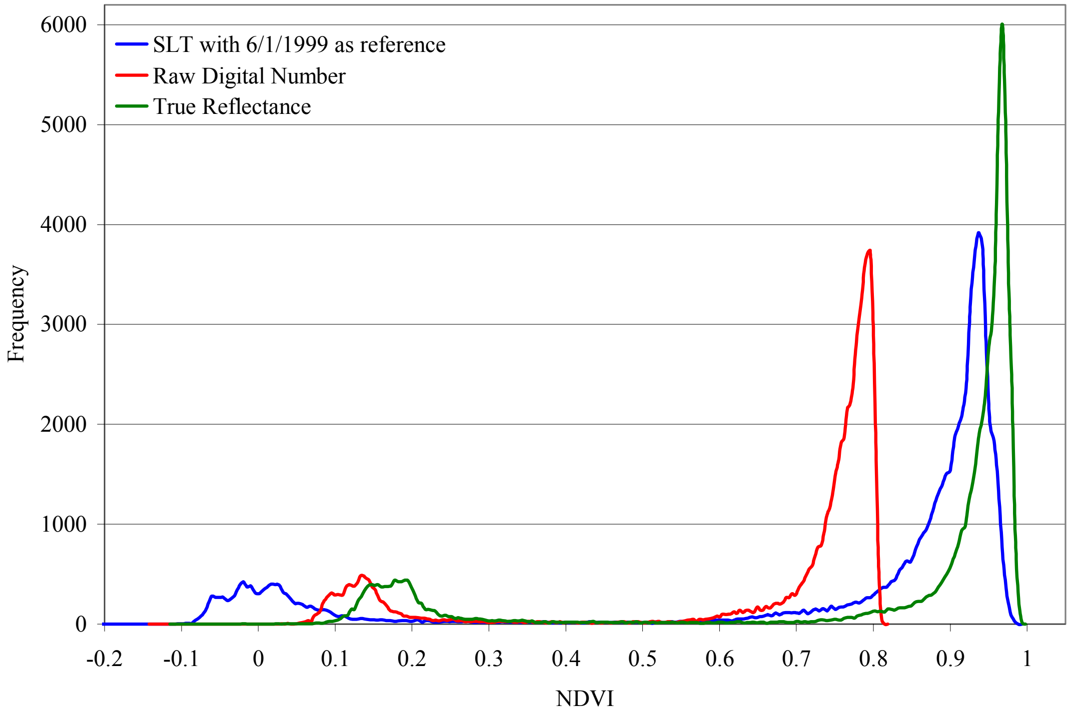


Figure 29. Histogram of NDVI distribution on 7/20/1999 from the sub-image dataset

Figure 30 shows the third case when the SLT NDVI's has a higher mean than the true reflectance ones. An interesting to note though is that there are NDVI values which are higher than 1. This would only be possible when the numerator of the NDVI equation is greater than the denominator, since the equation is:

$$NDVI = \frac{(NIR - red)}{(NIR + red)} \tag{1}$$

The only possible way for this to happen is if the red band values are negative. This only happened in one of the ten images that were processed. The intercept estimated by the transformation program made some of the red band values to be negative, therefore explaining the NDVI values greater than 1. Since the soil lines were extracted manually, there was not much to be done in this case. When the program is modified though, there could be a check for the minimum red value, which would be the maximum allowed intercept.

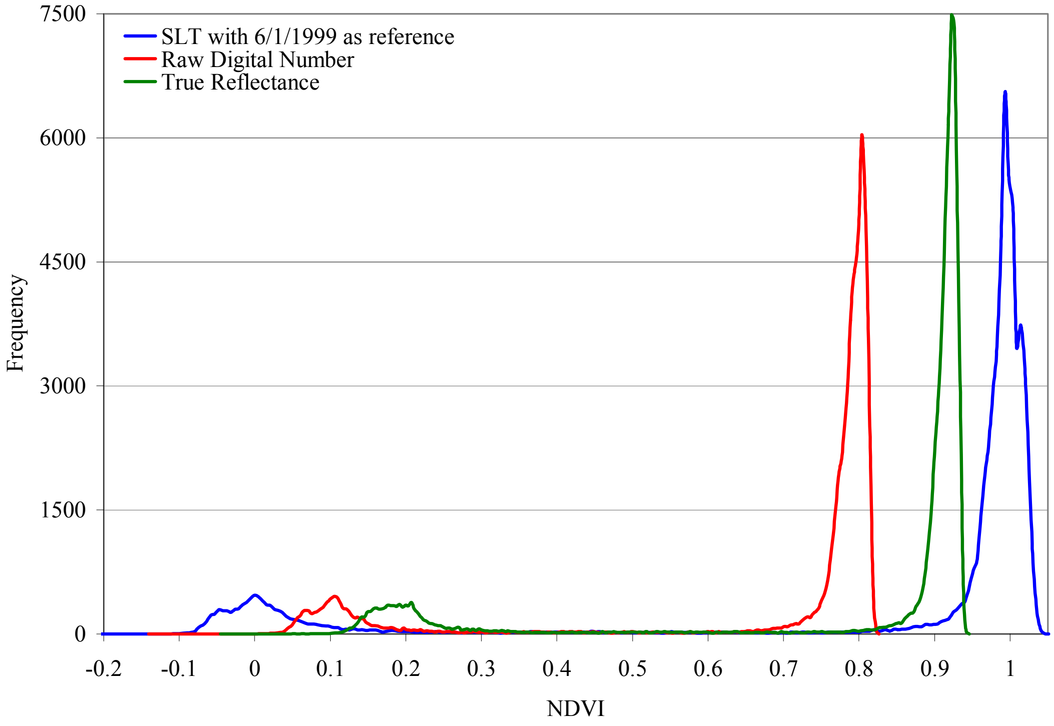


Figure 30. Histogram of NDVI distribution on 8/10/1999 from the sub-image dataset

The distributions of the histograms are quite similar, but the SLT is more stretched. The difference in the distribution of figures 28, 29 and 30, could possibly be attributed to the soil line parameters, which in this case were extracted manually. A soil line that is not so representative will end up affecting directly these histograms, once the transformation program uses the soil line parameters.

Figure 31 shows the temporal trend in mean NDVI from the different methods. While on the first portion of the graph the slope of the SLT is very similar to the slope of the true reflectance, after the third date that changes. On the first three dates the means of the raw NDVI's are much closer to the true reflectance ones, but with different slopes. After the third date, the SLT NDVI's vary much more than the others. The SLT NDVI means are higher than the raw, but there seems to be no pattern for the change in slope.

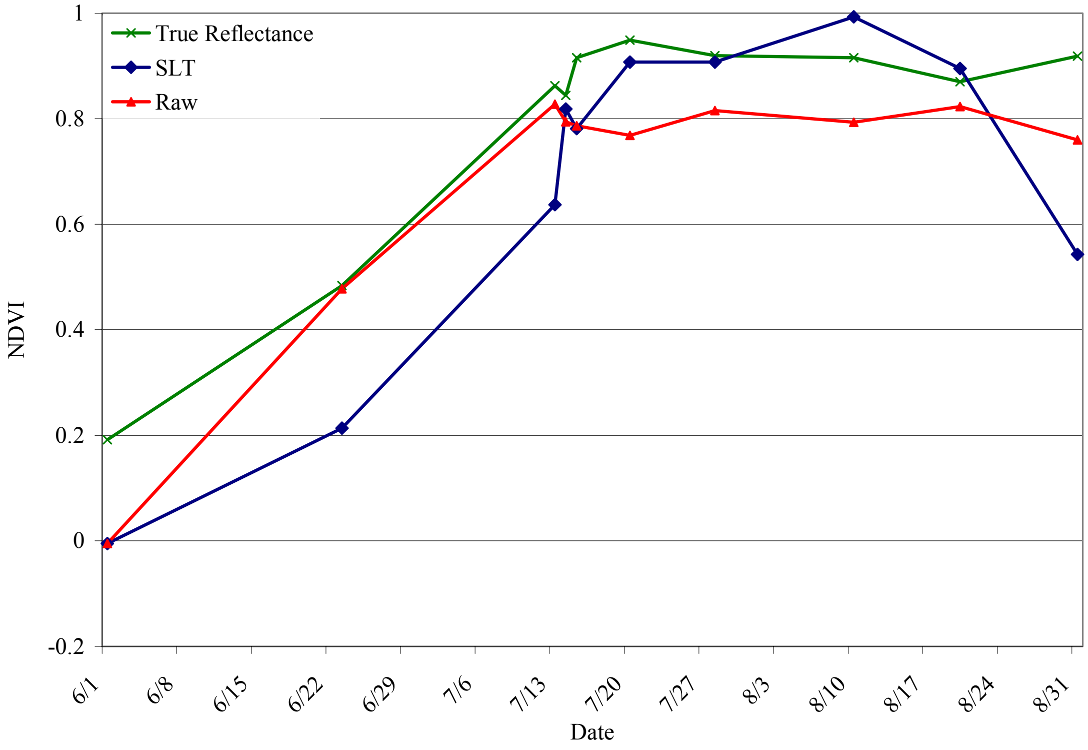


Figure 31. Temporal trends of the NDVI's for all different methods

The interesting thing to note is the change in true reflectance NDVI's on the 3rd, 4th and 5th dates. Images were acquired on 7/13, 7/14 and 7/15; therefore the change in true reflectance NDVI should not be so significant. What this shows is that there is some difference in imaging conditions, either on the camera or on the atmosphere that would explain this change in NDVI of 0.07 from one day to another.

The sub-image dataset leads us to say that the SLT technique has a potential for normalizing multi-temporal images, if the soil lines are calculated correctly. The differences in the WHOLE and sub-image are mainly attributed to the soil line extraction technique, while in the first case it was done automatically by the program, in the latter case soil lines were plotted manually. The auto correction program was used in the same fashion for both datasets, but, in the sub-image approach, “C” values were variable and the parameters used were those that maximized the significance of the regression.

In the studies published previously, results from the automated soil line extraction are promising. The soil line theory relies strongly on the extraction of a significant soil line. The automated extraction though has still to be investigated, to determine an optimal bandwidth for locating minimum NIR values in the red band. The minimum Euclidean distance for use in the transformation program has also to be optimized and while in some cases a value of 10 is sufficient, in others, 20 is more significant. Previous work shows that the SLT transformed images predicted corn growth patterns very well, with at least 87% of pixels changing in the expected manner (Fox et al., 2003). In another study by Fox et al. (2004), the soil line extraction program did not perform as well, once in one of the images the program extracted an “unreasonable” soil line, with negative slope.

Changes to the software, such as using a range of red values for locating the minimum NIR value could improve automated soil line extraction. Previous calculation of NDVI values and plotting of histograms could assist in determining a rule for bare soil pixels (e.g.: NDVI < 0.5), which could then be used for determining the soil line. A minimum and maximum allowed slope, or NIR to red ratio, could be used for improving detection of the soil line.

SUMMARY

The use of soil lines for normalization of multi temporal images has still to be investigated further. Limitations to the current method are due to poor soil line equations being extracted automatically. The dataset tested here had a higher radiometric resolution than other datasets tested previously. This impacted the quality of the soil line, and therefore of the SLT technique.

The WHOLE dataset showed the inconsistency of the soil lines when these were extracted from an area that contained different features. The automatically extracted soil lines were not representative of bare soil pixels. An analysis of the cluster of points that fall within the soil lines showed that the line was greatly influenced by the reflectance tarps and water bodies.

The sub-image dataset also indicated that the soil line extraction program was not very effective in detecting the true soil line. Negative slopes and absence of intercept values were indicators of such. Once soil lines were manually computed, and the transformation program used, the SLT's performance changed. Even though it did not consistently follow the trends of true reflectance NDVI, it did, in some dates, have a superior mean value. When trying to detect temporal trends, though, it is interesting that the slopes of the SLT method followed that of the true reflectance. In this case, the SLT calculated NDVI did follow the trend of the true reflectance on the first three dates. Once the vegetation was established, the trends of the SLT and raw NDVI's did not consistently follow the true reflectance. The true reflectance NDVI's had a significant change on images taken on three consecutive dates. That was not expected, since the cotton crop should not have changes of that magnitude within one day.

The existing programs for performing the SLT did not perform well on this image dataset. Possible causes for extraction of bad soil lines are: 1. interference from other features in the scene, such as water bodies, reflectance tarps and others that might have lower NIR values for each red value if compared to the soil points; 2. absence of pixel values that fall within the soil line. When a minimum NIR value for a red value falls on the vegetation portion of the plot, it influences the soil line to have a high intercept and possibly negative slope.

Once there is an accurate soil line, the process performs quite well in detecting change. The manually extracted soil lines were representative in some cases, but the extraction method is subjective and depends on the user to decide where the best line should fall. A more robust method, in which the soil line would be selected automatically, would greatly increase significance of the SLT. Isolation of soil pixels can be done in RSI ENVI 4.1®, and the same software also has capability of doing supervised and unsupervised image classification, that could assist in identifying bare soil pixels. Another possibility is to change the current soil line extraction program so that it searched for a minimum NIR value for an interval of red values. This interval could be variable, and the minimum NIR within it considered being on the soil line.

The current process of the SLT is quite cumbersome and improvements in the software are suggested. Images should be read from a variety of formats, and therefore the ArcView® script eliminated. When calculating the soil line, the program should allow variable bandwidths on the red band for locating true soil pixels. Once the soil lines are calculated, the transformation program should allow the user to specify the "C" value for the second regression. The use of ArcView® for extraction of the ASCII files can now be surpassed, and minor modifications to the ENVI ASCII output are necessary, so that the files can be used by the soil line and auto correction programs. There should be a check in the software limiting the transformation intercept for the red band. If an intercept greater than the minimum red band value in the image is calculated, NDVI values greater than 1 will result for some pixels.

CONCLUSIONS

The SLT technique has potential for normalization of multi-temporal images. Current limitations due to the soil line extraction program prevent it from being useful in the current form.

NDVI detection is improved by the SLT technique when there is a low amount of vegetation, but once NDVI's are high, the SLT did not perform well in this image dataset.

FUTURE RESEARCH

Investigation of different methods of soil line extraction and optimization of the algorithm are to be done. Incorporating either a maximum red to NIR ratio or a range of slopes is to be studied. Selection of minimum NIR reflectance values for each red, which is done currently for every red value, can possibly be optimized, by selecting minimum NIR values within a bin of red values.

Use of supervised and unsupervised image classification, to separate bare soil pixels from pixels with vegetation is a promising future for optimal automated soil line extraction.

Improvement of the soil line program, to a more modern programming language such as Visual Basic (VB), is a task that has been initiated. This is to be done, not only to simplify the process, but also to increase its significance, by allowing for changes in “C” values and variable ranges for locating minimum NIR values. The soil line extraction and transformation programs are to function as one stand-alone application. This program will: extract the soil line, display the soil line and a plot of red vs. NIR, possibly allow selection of bin size, allow variable “C” values and will output a text file with all the parameters. Currently images have to be separated in red and NIR bands, and processed as ASCII files. Two solutions to this approach are suggested. If the new program is written in VB, once can select an image type and implement that. Another solution is to do the process in RSI IDL®, which would enable multiple image formats to be read.

CHAPTER V

SUMMARY AND CONCLUSIONS

The use of site-specific data can greatly enhance the value of information for crop management. The use of historical height and yield maps can assist in selecting potential representative sites within a field. If the field is of low variability, this methodology will allow for one or two sites to characterize the whole field, while COTMAN recommends a minimum of four sampling sites per field. Highly variable fields should have at least one sampling site for each uniform area within it. Another solution would be to establish management zones. Zones of lower variability can then be sampled with fewer sites and increased data value.

Mepiquat chloride can be effectively applied in variable rate and future research is necessary to prove the method efficient, but variable rate application was shown to work. Weather conditions did not allow a comparison of the variable rate with the fixed application. The system is functional, but some modifications are suggested to improve the overall efficiency of the system. Reduced change in rate of application is suggested so that the system can respond promptly.

The SLT technique is an effective means for multi-temporal image normalization if the automatically extracted soil lines are representative of the true soil line. The soil line extraction program, however, needs some improvement to select representative soil lines. The transformation is significant when there is low vegetation, but does not seem to respond very well when there is a lot of vegetation.

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APPENDIX A

HOW TO CREATE MAPS WITH HISTORICAL HEIGHT AND PREVIOUS M.C. IN AGIS

To get a prescription map in the VAF format, to be used with Pocket Spreader, there are a few things to follow. This document describes how to have a prescription map as a grid, with cells being assigned a value as follows:

- HHHRR.R – which mean the first 3 digits will have the historical height information, while the three last digits will be the previously applied M.C. application rate.
- The DAT file, generated by H-MAP, should be processed with the Process.exe.

It will output a text (.txt) file and a filtered (.csv) file. With the filtered file:

- You must import the data in SSToolBox as X Y coordinates, and then you must edit the file and add a field. Using the Map Calculator, you will add values (1000*Plant_height). Be sure that the height values follow the format as described above (HHH00.0), since the rate values will be added later. Create a surface (IDW power 2 as the interpolation method). After the surface has been created, export it as a shape file.

Once you have the shape file, you must open AGIS.

- In AGIS → Tools → Surface Generator
- In surface generator, you must have a drawing file that will be your boundary.

- If it consists of more than one polygon, go: Surface → Boundary Objects, then left click on you boundary. It will turn red. Go to File → Point File and chose your source file.
- In this case you will browse to the .dbf file of you shapefile.
- Select the appropriate Projection and Datum, hit Finish.
- A box will appear in which you will have to put the field that corresponds to latitude, the field that corresponds to longitude and the Z coordinate (in this case, your height*1000). Hit Ok, and OK again.

Now we will create the surface in AGIS.

- You should be seeing your boundary image in red and your data in green.
- Go to surface → Nearest neighbor…
- Select a radius of influence that is the size of the cell you used previously to create your surface in SSToolBox .
- Uncheck the Test Box
- Set you pixel size once again to the same you used in SSToolBox and hit OK.
- Another Box will come up, pick a name for your layer, set the units as Special and Precision to 0. Hit OK.
- Go to File → Exit and that will close the surface Generator window

You should have a new theme on the right hand side of your AGIS table, if you don't it's because you used the same layer name as at a previous attempt, so right click on the layer name you picked and hit files. You should have at least two themes; uncheck the one you don't want and hit apply.

APPENDIX B

GEO-REFERENCING AND HOW TO USE THE SLT

Geo-referencing statistics for the SLT images:

- Georef 2846 Based on 2846n_geo (8 points Selected)
- RMS – 0.971313
- Points file – geo2846.pts

Original File	Imaging date	RMS
2241	6/1/1999	0.238832
2483	6/23/1999	0.219122
2746	7/13/1999	0.397854
2797	7/14/1999	0.202324
*2846	7/15/1999	0.971313
3048	7/20/1999	0.413454
3305	7/28/1999	0.276538
3569	8/10/1999	0.218072
3939	8/20/1999	0.137437
4050	8/31/1999	0.272566

Images were geo-referenced and resized in ENVI and saved in LAN format (ERDAS) to keep 12-bit information.

Grids were made from the multi-band images, where

BAND 1 = RED

BAND 2 = Green

BAND 3 = NIR

The grids were generated in ArcView 3.3, with filenames and band names associated. 2241red, means image 2241 red band grid.

After grids were generated, An ArcView Script (copied from AV_SLT_MS_150.txt), was used to generate the ASCII files. The script also generates text files with the path to the ASCII files, and that is what is read by the SLT program so be sure to have the .asc files in the path indicated by the corresponding image text file (rfimg_r.txt, rfimg_ir.txt, img2_r, img2_ir.txt and so on...)

The SLT Program was used (Soil_lines12bmod) in order to calculate the soil lines for each image.

It generates Ref_SL.txt and subsequent Img*TBC_SL.txt (where * = image number)

The AutoCorr_eq is to be used after the Soil_lines12bmod in order to calculate the normalization equations for the different bands in the different images, outputting Image*_CorrEq.txt (* = image number).

And then apply the regression coefficients to images and calculate NDVI. That can be done in ENVI. Open ENVI, then open file, select the image to which you want to apply the corrections. On the ENVI menu go to: Band Math and input the desired equations, an example follows:

```
(((B3*0.9906)-330.6279)-((B1*1.5377)-79.0774))/(((B3*0.9906)-330.6279)+((B1*1.5377)-79.0774))
```

B3 – corresponds to NIR

B1 – corresponds to Red

This equation will calculate the NDVI image utilizing the parameters input by the user. The output is another image that can then be saved for analysis.

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