A PLANT HEIGHT SENSOR FOR REAL TIME, VARIABLE RATE APPLICATION

A. D. Beck and S. W. Searcy
Agricultural Engineering Department, Texas A&M University
College Station, TX

Abstract

To optimize the application of chemicals, a real-time variable rate system has been developed. The project incorporated an optical sensor that continuously measured plant height, cotton growth relationships in the MEPRT (**MEP**iquat Chloride **R**ate and **T**iming) software and a chemical rate controller into a single system. The plant height sensor was the continuation of a system initially evaluated in 1997. When used to predict the plant height in the field, the sensor was accurate a week after the pinhead square growth stage, and systematically overestimated the height at the first white flower. Pix application at the later date resulted in higher application rates than necessary. However, the height sensor was consistent in measuring consecutive passes through the field. Alternating passes of variable and uniform rate application were used. The average variable rate was higher in one field and lower in another compared with the applied uniform rate. This was due to the estimation of the average field height in both fields. Overall, the real-time system performed as it was designed.

Introduction

Cotton (*Gossypium hirsutum*) is a perennial plant that is grown as an annual crop. It is also an indeterminate plant that will continue to form fruit organs whenever growing conditions permit. The number of fruiting organic and the vegetative growth of the plant are affected by the available nutrients and moisture, meteorological conditions and the concentration of the growth hormone, mepiquat chloride (Pix®). Varying local conditions, particularly available soil moisture, can result in dramatic differences in plant growth patterns across a field. Pix controls the partitioning of photosynthetic energy between vegetative and fruit organ growth. By optimizing the Pix concentration in the plant, growers can maximize yield while maintaining a more uniform plant size to facilitate harvest operations.

The need for Pix is determined by the growth patterns of the cotton plants across a field, which is related to the stresses that the plants experience. Moisture stress is perhaps the most common limiter of plant growth, and is often highly variable within a field. Thurman and Heiniger (1998) conducted intensive grid sampling of a cotton field in North Carolina at two resolutions (0.3 ha/sample and 0.1 ha/sample). They found that random sampling, as practiced by crop consultants, underestimated the variability of plant height within the field. They concluded that plant height variability was great enough to justify variable rate application of Pix. Studies of variable rate application have had mixed results. Munier et al. (1994) compared variable applications to fixed rates on California cotton fields, and found a fixed rate to provide a better economic return. A sprayer operator who judged the plant size and turned on appropriate nozzles determined the variable application. Thurman and Heiniger (1999) used aerial photography, soil surveys and field history to determine areas of slow and fast growing plants. Pix was applied in uniform and soil-specific rates. They found that the variable treatments had a 51-74 kg/ha yield advantage over the uniform treatment.

If variable rate applications of Pix are to be used, both a relationship to optimize the rate and a timely, inexpensive means of assessing the plant size are needed. The optimum Pix application rate has generally been established as a concentration of 10-12 ppm (Landivar et al., 1995). To obtain this concentration, the plant biomass per area must be determined. Cotton producers have been provided with a suggested practice to determine the biomass and the optimum application rate for Pix. This practice indirectly estimates plant biomass by measuring plant height. Landivar et al (1998) showed that until two weeks after first bloom stage, cotton biomass is linearly related to plant height. Landivar developed a software program (MEPRT, **MEP**iquat Chloride **R**ate and **T**iming) that would suggest optimum Pix rates when provided plant height, density and the number of nodes. Since the number of nodes can be predicted by the days past emergence (3 days = 1 node) and plant density is often fairly uniform, cotton height is the determining factor. Unfortunately, taking manual plant height measurements is time consuming. As a result, most producers use a field average to determine the Pix growth regulation application rate. A more desirable approach would be to apply the growth regulator with a real time control system. Such a system would require a continuous plant height measurement as the sprayer moved through a field.

Development of a plant height sensor was initiated in 1997 at Texas A&M University with two alternative designs, mechanical and optical. The mechanical system consisted of horizontally mounted fingers that could swing back when contacting the plant. The pattern of fingers in the normal and displaced positions could be interpreted to give a plant height estimate. That sensor was evaluated in 1998, and provided acceptable but less accurate performance than the optical sensor.

The optical sensor was based upon the blockage of light beams by plants that pass between the light source and detector. A vertical column of light emitter and detector pairs is referred to as a light curtain. Figure 1 illustrates the application of the light curtain with a cotton plant. A blocked beam was interpreted as a “one” and unblocked as a “zero.” The plant height could be estimated by the binary pattern obtained by scanning the detector array.

The task for the cotton plant height estimation algorithm was to determine the average height from the soil surface to the growing tip. In the 1998 version of the system, the system had a maximum scan rate for the light curtain of 9 Hz. Each scan of the light beam array was recorded and later processed. The highest blocked beam for each scan was determined to be the plant height. A moving average of the highest blocked beam was found to be necessary, as the individual scans were highly variable. An equation was developed for plant height with days after emergence and a 5 m moving average of top blocked sensor heights as the two independent variables. The 95% prediction interval for cotton plant height estimation was ±3.3 cm (1.3 in.) (Stewart, 1998).

In 1999, the height estimation was modified to utilized information from all of the beams. The hypothesis behind the modified algorithm was that the upper part of the cotton plant has a characteristic conical shape, and that the blockage of the beams should follow that same pattern. Figure 2 shows an expected shape of the histogram of blocked beams, which presented several uncertainties relative to the extraction of the mean plant height. Using the beam values M, A and B, the height beam (H) was calculated and the plant height was estimated. Evaluation was performed late in season, with plants past cutout, but prior to significant defoliation. The individual plots varied dramatically in RMS error because for a few row sections, the modified algorithm significantly over and underestimated the hand measurements. The majority of comparisons were more reasonable.

In 2000, the percentages used to calculate the location of beams A and B were changed to 75% and 25% of the maximum. The height sensor was also spanned across two rows to reduce the variability seen with a single row. The RMS error was reduced to less than 6.5 cm and the trends through the field were mostly tracked. This improved accuracy may be attributed partially to the scanning of two rows and partially to evaluation at an earlier stage of crop development (Searcy and Beck, 2000). With the improved accuracy of the sensor, extending its capabilities for a real-time variable rate Pix application was explored.

Reprinted from the *Proceedings of the Beltwide Cotton Conference*
Volume 1:307-311 (2001)
National Cotton Council, Memphis TN

Objectives

1. Evaluate the ability of the height sensor to estimate plant height along the machine path and across the boom width.
2. Evaluate the real-time control of Pix using the MEPRT software relationships.

Discussion

Real Time Variable Rate Application System Design

The optical sensor developed over the past three years was ready to be used in a real-time variable rate application system. The variable rate application system incorporated a plant height sensor, the MEPRT relationships, and a chemical rate controller. The system program was loaded and executed on a Wag Vision Control Device (VCD). When the plant height was determined for a section of row, the optimal Pix application rate could be calculated. The height-to-biomass relationships used in the MEPRT software were incorporated into the height estimation program. Every second an estimation of the plant height was calculated. Using this height and an operator provided average number of nodes, plant density and row width, the MEPRT software predicted the plant biomass. Based on the desired concentration of Pix in the plant and previous application rates, MEPRT calculates the optimal Pix application rate.

A Raven SCS 750 rate controller was used to regulate the flow of the main tank and five possible injection modules. Testing was conducted to determine the lag time when using one injection module to deliver the desired chemical. Driving 8.0 km/h (5 mi/h) and applying 15 gal/ac of carrier fluid, the delay before changing the concentration at the nozzle was 41 seconds, or 91.6 m (301 ft) of travel. This lengthy delay was clearly unacceptable. To avoid this delay, the Pix was mixed directly in the main tank. The amount of Pix added allowed for 15 gal/ac of liquid to be applied with the concentration desired for a uniform application.

The optimal Pix application rate was sent to the Raven controller through a serial communication port. The transmission between the VCD and Raven controller was an ASCII string with identification characters at the beginning of the string to determine the type of message. The Raven controller also transmitted data to the VCD, such as the actual flow rate, distance and area covered for the field and machine, and the volume of liquid remaining in the tank. Data from all the instruments was geo-referenced and recorded on a PCMCIA card.

Experimental Procedures

One week following pinhead square stage, the plant height was recorded across two 8.1 ha (20 ac) fields. The sensor was mounted behind the sprayer spanning two rows. For every pass of 18 rows through the field, heights down two pairs of rows were measured. Rows 6 and 7 were recorded from the control rows, and rows 10 and 11 from the Pix applied rows. Hand measurements were also recorded for the first 30 m along 10 passes for each pair. To verify the accuracy of the sensor, the hand and sensor data was smoothed and resampled to obtain a best estimate of height at a common point. Estimates were made each 2.5 m along the row, and any data within 2.5 m before or after the point of interest were included in the average. Interpolated maps of plant height were created using ArcView 3.2 Spatial Analyst. A height difference was calculated between the control and Pix applied maps.

Before the second Pix application at first white bloom stage, plant heights were again recorded throughout both fields. However, the sensor was mounted on the front of a high clearance sprayer spanning two rows (see Figure 3). Two pairs of rows were again recorded for each pass, and the same procedure to determine the accuracy of the sensor as before was followed.

Visible height variability in the field justified attempting to use a variable rate Pix application. For the Pix application, alternating passes of variable and uniform rates were applied (see Figure 4). This produced four paired blocks in Field A and seven paired blocks in Field B for data comparison. The uniform application rate was calculated by MEPRT using the operator determined field average plant height as predicted by the sensor. Each field application rate was calculated based on individual field conditions. Field A was determined to have an average plant density of 10.5 plants/m (3.2 plants/ft) and the average number of nodes per plant was 14 nodes. The average plant density in Field B was 8.5 plants/m (2.6 plants/ft) with an average of 13 nodes per plant. The variable application rate was predicted with MEPRT using the continuously measured plant height across rows 9 and 10 and the same field averages mentioned previously. Measuring row 10 in both tests allowed a test of consistency of the sensor and variability in height seen between two different rows. The plant height map was interpolated and subtracted from the height map created from rows 10 and 11. This difference was used to evaluate the variability seen between two consecutive pairs of rows.

Although the sprayer covered 18 rows, only two were measured by the sensor. To determine the height variability across the spray boom, 20 locations in each field were sampled on July 18. The heights of all 18 rows were hand measured parallel to the boom. Rows 5 through 8 were removed from analysis since they did not receive Pix during application. The average height and standard deviation were calculated for each sampling location.

Results

Measuring the plant height one week after pinhead square resulted in height estimation RMS errors from 2.4 – 6.5 cm (0.94 – 2.56 in). Figure 5 shows the raw hand and sensor height data. Much variability is present between consecutive hand measurements while the sensor data is smoother since the distance between height estimations is greater. Generally, the sensor data followed the overall height trends throughout the field.

When using plant height to calculate the Pix application rate at first white flower, the sensor systematically overestimated the plant height. Figure 6 shows smoothed height data from both hand and sensor measurements along two rows. The sensor consistently predicted greater heights, but the trends seen in the crop height were characterized with the sensor. The RMS error ranged from 7.0 to 14.0 cm (2.75 – 5.51 in). This error was greater than experienced with measurements recorded two weeks earlier. A scatterplot of the hand and sensor measurements revealed that the relationship was linear (Figure 7). An exact cause to the problem was not known, but it hints to the possibility that the sensor estimates could be susceptible to different growth stages in the cotton. This sensitivity to growth stage was also indicated in earlier results, when including the date in a regression equation gave more accurate height predictions (Stewart, 1998). More information could be extracted from the histograms, possibly reducing the sensitivity of the height estimates to the growth stage.

With a consistent overestimation of height, differences in the three measurements through the field can be calculated. Figure 8 shows the height down two entire passes of Field A. The control rows were usually taller than either of the Pix treatments. After interpolating the height maps, a height difference map can be created. Figure 9 shows the difference between the control and Pix applied height map in Field A. In most of the field, the control rows were taller than the Pix applied rows. The RMS difference was 11.9 cm (4.7 in) for the point measurements. This would be expected since Pix is intended to reduce the stem elongation rate when applied. Subtracting the two height maps in Field A created from the Pix applied and application rows, a large percentage of the field was within +/- 2.5 cm (1 in). Some areas show a greater difference in which the error cannot be accounted. The RMS difference in the point height measurements was 3.2 cm (1.3 in). Field B height measurements resulted in similar maps and conclusions.

The second Pix application of the season was made by alternating variable and uniform rate treatments in adjacent passes. Based on the MEPRT predictions with the operator determined average field height, the uniform application rates in field A and B were 4.8 and 4.9 oz/ac, respectively. It was expected that the average application rates in the variable treatments would be close to the uniform rates. However, for Field A the average variable application rate was between 6.2 and 7.1 oz/ac for the four blocks. The variable rate treatments in Field B required less Pix than the uniform application, only 4.2 – 4.7 oz/ac. This difference can be contributed to the operator-estimated height used to predict the uniform application rates. If the entire field was variably applied, this difference would not be noticed.

To determine if two rows can adequately predict the average height across the entire boom, the 18 rows parallel to the boom were measured. The control rows were discarded from the analysis. Figures 10 and 11 show two passes with four locations sampled per pass. In Pass 1 of Field A, great variability was seen across the rows measured. The vertical lines indicate the rows that would be measured with the sensor. These rows may or may not adequately characterize the unmeasured rows. Less variability was noticed in Pass 3, and the two measured rows might describe the rest of the rows better than the two rows in Pass 1. Table 1 indicates the average height and standard deviation per location. Wide ranges of average height was noticed with an average standard deviation in the fields more than three times the accuracy of the sensor (1.9 cm or 0.75 in). Although in some locations, a portion of the boom width deviated in height from the measured rows, it should be remembered that this conditions exists with uniform application rates as well, but is ignored.

The resolution of the variable rate system at this growth stage was examined. Using MEPRT with the average field density and number of nodes in Field A, several heights were used to calculate different application rates. Table 2 shows that the average height in Field A will require 4.40 oz/ac of Pix. Adding the resolution of the sensor to this height results in an increase of 0.35 oz/ac in Pix. Increasing the average plant height by the one standard deviation of the measured heights (7.3 cm or 2.9 in) increases the Pix application rate by 1.43 oz/ac. If a farmer desired to adjust the Pix application rate on 1 oz/ac increments, the variable rate system could be used.

Summary

The plant height sensor, cotton growth relationships and chemical rate controller were successfully integrated into a real-time, variable rate Pix application system. The plant height sensor was tested for accuracy along the row and across the boom width. The sensor estimated the plant height within 2.4-6.5 cm the week following pinhead square stage, but systematically overestimated the height at the white flower stage by 7.0-14.0 cm. However, the sensor was consistent in measuring consecutive rows of data. An interpolated difference map showed that the height of the control rows was greater than the Pix applied rows. The height estimates resulted in a higher application rate than needed, but the difference in the amount of Pix applied corresponded to the differences in the plant height along the row. A limitation of the system was measuring only two rows out of the entire boom width.

References

Landivar, J. A., D. Locke, Z. Cespedes and D. Moseley. 1995. The effect of estimated plant concentration of Pix on leaf area expansion and main stem elongation rate. Proceedings of the 1995 Beltwide Cotton Conference. 1081-1085.

Landivar, J. A., J. T. Cothren and S. Livingston. 1996. Development and evaluation of the average five internode length techniques to determine time of mepiquat chloride application. Proceedings of the 1996 Beltwide Cotton Conference. 1153-1156.

Landivar, J. A. 1998. The MEPRT method to determine time and rate of mepiquat chloride application: uses and misuses. Proceedings of the 1998 Beltwide Cotton Conference. 1414-1416.

Munier, D. J., S. D. Wright, B. L. Weir and T. A. Kirby. 1994. A two year summary of applying Pix at variable rates when plant height varies in a cotton field. Proceedings of the 1994 Beltwide Cotton Conference. 1257-1258.

Searcy, S. W. and A. D. Beck. 2000. Real time assessment of cotton plant height. Proceeding of the 5th International Conference on Precision Agriculture. In Press.

Stewart, J. H. 1998. Cotton height measurement and variable rate chemical control. Unpublished Master's Thesis. Texas A&M University, College Station, TX.

Thurman, M. E. and R. W. Heiniger. 1998. Using GPS to scout cotton for variable rate Pix (mepiquat chloride) application. Proceedings of the 1999 Beltwide Cotton Conference. pp. 1499-1502.

Thurman, M. E. and R. W. Heiniger. 1999. Evaluation of variable rate Pix (mepiquat chloride) application by soil type. Proceedings of the 1999 Beltwide Cotton Conference. pp. 524-526.

Acknowledgements

The authors wish to gratefully acknowledge the support of Cotton Incorporated, the King Ranch, John Deere and the Texas Agricultural Experiment Station for this study. We also acknowledge the assistance of Jason Stewart, whose Masters research started the height sensor development, and Juan Landivar, who was an important contributor to the precision cotton management project

Table 1. Height variability measured across width of the spray boom at 20 location in each field.

Data	Average Height (cm)	Std Dev of Height (cm)
Field A Sites	57.0 – 102.5	2.6 – 14.5
All Field A	73.0	7.3
Field B Sites	65.1 – 110.4	4.5 – 14.9
All Field B	77.3	7.9
Both Fields	75.2	7.6

Table 2. Pix application rate resolution calculated with statistics from Field A. Height along with average plant density (3.23 plants/ft) and number of nodes (14 nodes) input into MEPRT to determine Pix application rate.

	Height (cm)	Pix application rate (oz/ac)
Field A	73.0	4.40
	+1.9	+0.35
	+1 σ	+1.43

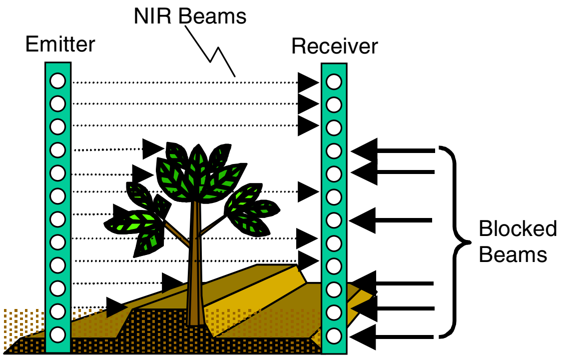

Figure 1. Light curtain with a cotton plant blocking some of the beams.

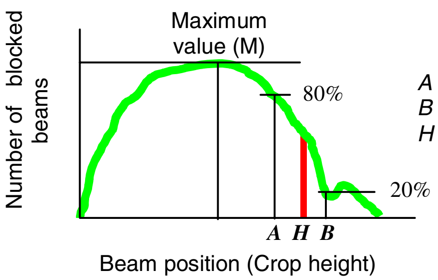

Figure 2. Hypothetical histogram of blocked beam frequency. A, B and H show the points used to estimate the plant height.

Figure 3. Optical height sensor mounted in front of high-clearance sprayer.

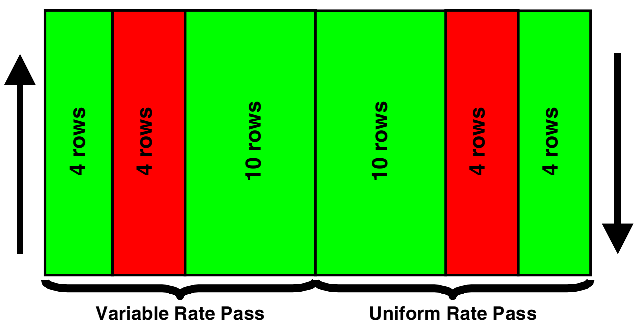

Figure 4. Experimental design used for comparison of treatments. Darker control rows received no Pix during entire season.

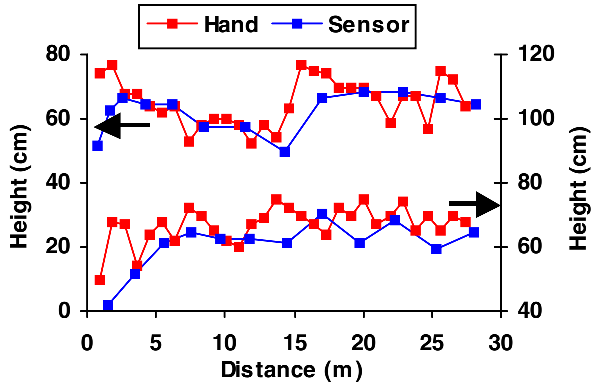

Figure 5. Height measured down the rows at pinhead square. The sensor generally tracked the height trends down the row.

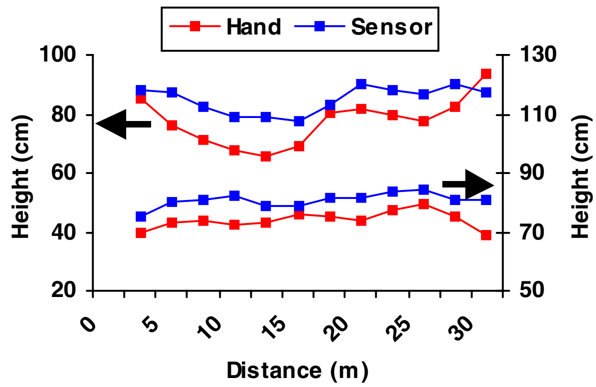

Figure 6. Height measured down the rows at first white flower. The sensor systematically overestimated the height, but continued to follow the trends in the field.

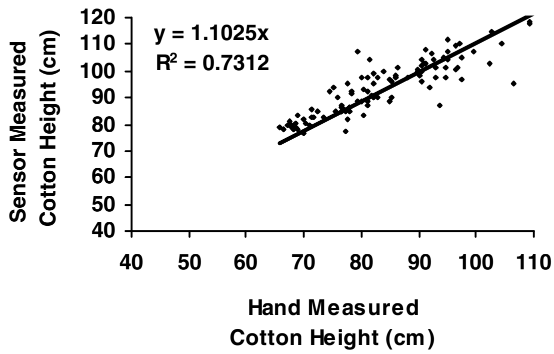

Figure 7. Comparison of sensor versus hand measured height data.

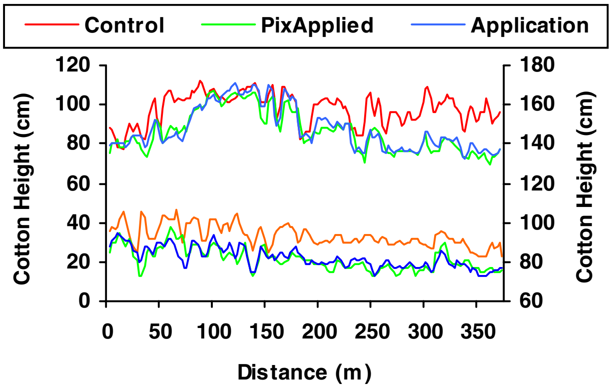

Figure 8. Height measured along pass. Control was taller than the rows with Pix application. The consecutive rows in applied region mostly match.

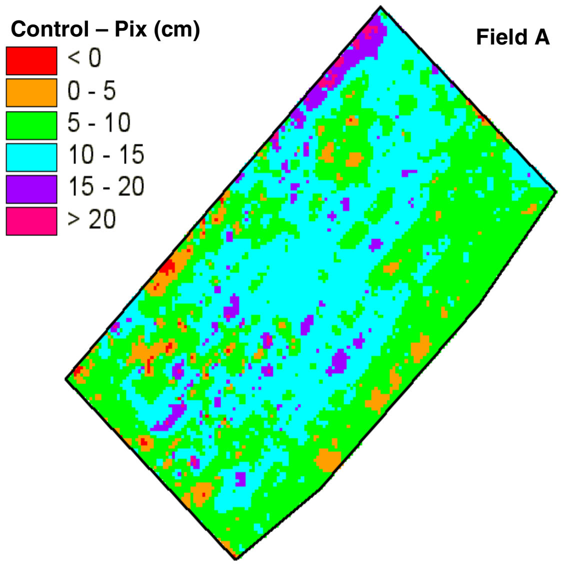

Figure 9. Difference between interpolated maps between control rows and Pix applied rows. The difference was mostly greater than 0.

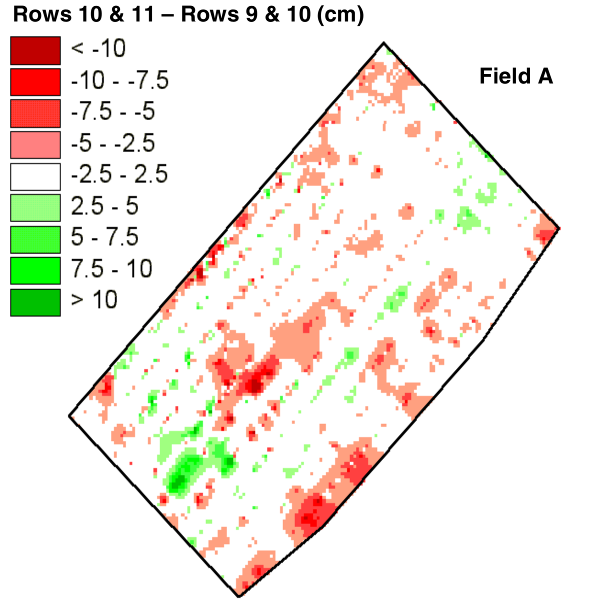

Figure 10. Difference between consecutive measured rows. A high percentage of the field has a difference of +/- 2.5 cm.

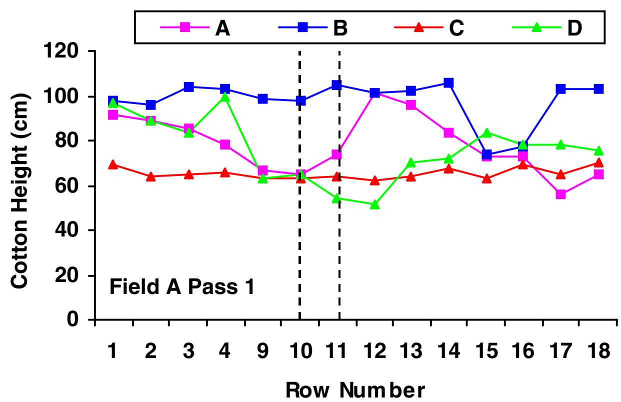

Figure 11. Height measured across width of boom for Field A Pass 1. Two dashed lines indicate two rows measured to characterize the entire all rows.

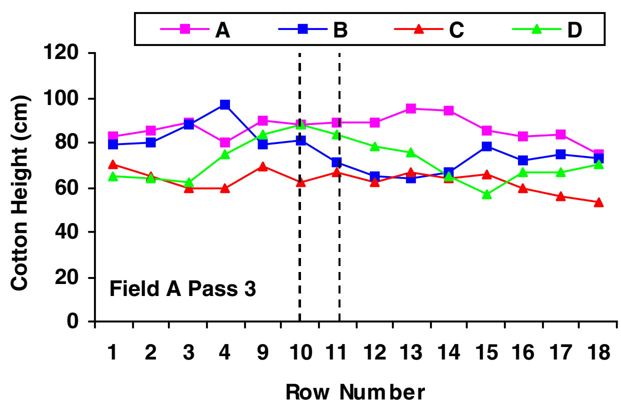

Figure 12. Height measured across width of boom for Field A Pass 3. Two dashed lines indicate two rows measured to characterize the entire all rows.