2005 Beltwide Cotton Conferences, New Orleans, Louisiana - January 4 - 7, 2005

REAL-TIME PLANT HEIGHT MAPPING AND VARIABLE RATE APPLICATION OF GROWTH REGULATORS

Marcelo C. C. Stabile and Stephen W. Searcy
College Station, TX

Abstract

A prototype system for applying variable rates of mepiquat chloride according to the rate of growth of plants in a region of a field was developed and evaluated. The evaluation experiment included three treatments: control (no mepiquat chloride), single rate (according to Cooperative Extension Service recommendations) and real-time variable rate application of mepiquat chloride. Variable rate applications were based on the rate of growth of cotton and previous mepiquat chloride applications. Rate of growth was calculated based on the difference between the real-time heights and an interpolated previous height map. The MEPRT relation was used to determine the application rate of mepiquat chloride based on rate of growth. Even though applications were done late in the season, due to weather conditions, the areas where mepiquat chloride was applied in variable rate had significantly lower rates of growth than the other treatments.

Introduction

With the advance of precision agriculture and the developments of new farming equipment, it becomes 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.

Due to cotton characteristics, the need for mepiquat chloride, which will reduce its vegetative growth, will vary according to variety, soil, water stress, solar irradiance among many other factors. Farmers use mepiquat chloride to reduce vegetative growth so that they get a more uniform plant height, and therefore increase harvest efficiency. A consultant or farmer’s experience usually determines the rates at which mepiquat chloride is applied.

An 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).

With the development of new tools though, it has become possible to integrate historical with current data. By utilizing the HMAP system integrated to a PalmTop loaded with layers of previous mepiquat application rates, previous plant height and a DGPS, it becomes possible to calculate the plant’s rate of growth. With the rate of growth and knowing the previous mepiquat application rates, it is possible to calculate the application rate to achieve the desired concentration of mepiquat in the plant.

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 is that by utilizing a variable rate mepiquat application one will diminish plant height and variability in the field. The objectives are: to implement the real time variable rate application system, test it in the field and to establish if the system significantly affects 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. It is desirable that the plant has 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 constant increase in yield, but did increase percent of final harvestable bolls by 5% and reduce plant height and main stem nodes by one (Kerby, 1985).

Cothren (1979) affirms 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) reports decrease of plant height by 26%, with increase in yield and yield attributes. Ketby 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. 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 be able 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 assumptions that individual internodes have their maximum length 12 to 15 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). When NAWF equals five, one can define that 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 the time of application 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 matchhead square stage until two week after first bloom. The MEPRT software calculates the rate of application by calculating the amount of mepiquat chloride needed to achieve the desired concentration of 12mg/kg (12 ppm). The program uses plant density, main stem nodes and plant height to estimate plant weight through regression. This is based on a strong correlation between plant height and weight during vegetative growth.

Ground or air broadcast spray has usually been the application method of mepiquat chloride. Alternatives to this technology have become available in the past few years. Stewart et al. (2001 a) 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 for fewer refilling of the application tank. Stewart et al. (2001 b) 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.

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 plant 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 in this case 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 in 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 consisting of five plants of which the height will 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 Beck and Searcy (2000) was used to measure plant height in the field during sprayer pass. The system would measure plant height and record GPS locations as well, therefore having a height map of the whole field. The program developed by Beck (2000) had a real-time application rate according to the height of the plant. Geiger implemented a system, which calculated a differential height from the previous interpolated height map and the current height. This differential divided by the number of days between passes would output the rate of growth (cm/day) and therefore trigger the MEPRT program that would calculate and appropriate application rate of mepiquat chloride. The RoG approach is more refined than just considering the height. In the latter case, taller plants, independently of their growth condition would always receive a high application rate, while the short plants would receive a smaller rate. In the RoG though, 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.

Material and Methods

An experiment was designed to test the 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) with five repetitions for a total of 15 experimental units. 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 1. Experimental plot

Experimental Unit	Treatment
1	VR
2	Fix
3	Control
4	VR
5	Control
6	Fix
7	Fix
8	Control
9	VR
10	VR
11	Fix
12	Control
13	Fix
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 for the sprayer to go in the field until plants were close to reaching cutout (NAWF<5). The sprayer was driven over every eight-row plot and mepiquat chloride was applied according to the treatment plan. On 7/6/04, 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, the fixed rate was 132 ml/ha (11 oz/ac), when the variable rate ranged from 0 to 239 ml/ha (20 oz/ac). The product applied was generic mepiquat chloride @ 3.8% 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.

Measurements were made to determine the accuracy and repeatability of the height measurements. Manual plant height along a row was collected on three dates. Plant height was measured every 0.6 m for 30 m. The measurement was an average over two rows and measurement areas were selected out of the variable rate experiment area. Areas of high variability were selected so that the data form the sprayer 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). It was driven at these two speeds in both directions, therefore having four measurements for each.

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 mini-array that scanned the array at 200 Hz and identified the blocked beams on each scan. The HMAP program calculated plant height by building blocked beam histograms. With these histograms, the height was set to be the value half way between 20 and 80% 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 were loaded in to 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 1. A brief description of the equipment used follows in Table 2.

Figure 1. Schematic 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 would then calculate the average internode length. If this was greater than 3.6 cm (1.4 in) and the added number of nodes greater than five or the average internode length greater than 3.0 cm (1.2 in) and added number of nodes greater than 4, then it would trigger the MEPRT program that would calculate the application rate. Growth rates less than the above received a zero rate.

Table 2. 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®	Model	114

AgGPS®	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

Each experimental unit was 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 any effect in yield. Another ANOVA was conducted on the average height of every treatment to check if there was increase in average plant height between measures.

Height maps were interpolated for each one of the dates in which data was acquired (7/, 7/15 and 7/22) using inverse distance weighted. This method was chosen to keep consistency with last year's data as in the method described by Geiger (2004). The interpolated height maps were then used to calculate rate of growth (RoG) maps, where:

$$RoG = \frac{height_{day2} - height_{day1}}{day2 - day1}$$

Two RoG maps were created (July 22nd –July 15th and July 15th – July 6th). Height data was classified to represent short, medium and tall plants on July 15th. RoG was then separated by the treatment that plants received and the height class to which they belonged. An unbalanced ANOVA was done for the whole dataset and then done as well for each RoG date. The reported sums of squares for the unbalanced data were type III sum of squares, since they are more appropriate. Interactions for height class, treatment and date were calculated for the whole dataset and for the analysis by date, interaction between height class and treatment was also considered. Mean comparison was done by Tukey's test for the balanced data and Tukey's Studentized range test was used for the unbalanced data.

Results and discussion

The effect of mepiquat chloride in increasing yield has been studied by many authors, but has not consistently shown. Particularly given the late application dates of this study, the treatments were not expected to have any significant effect in yield. This was confirmed by the ANOVA, in which there is neither effect of the mepiquat treatment nor effect from the replications.

Table 3. ANOVA table for the variable rate mepiquat chloride experiment

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

A plot of the experiment is show for illustrative purposes. Note that there are five replications of three groups of treatments. Allocation of treatments within the blocks was done randomly.

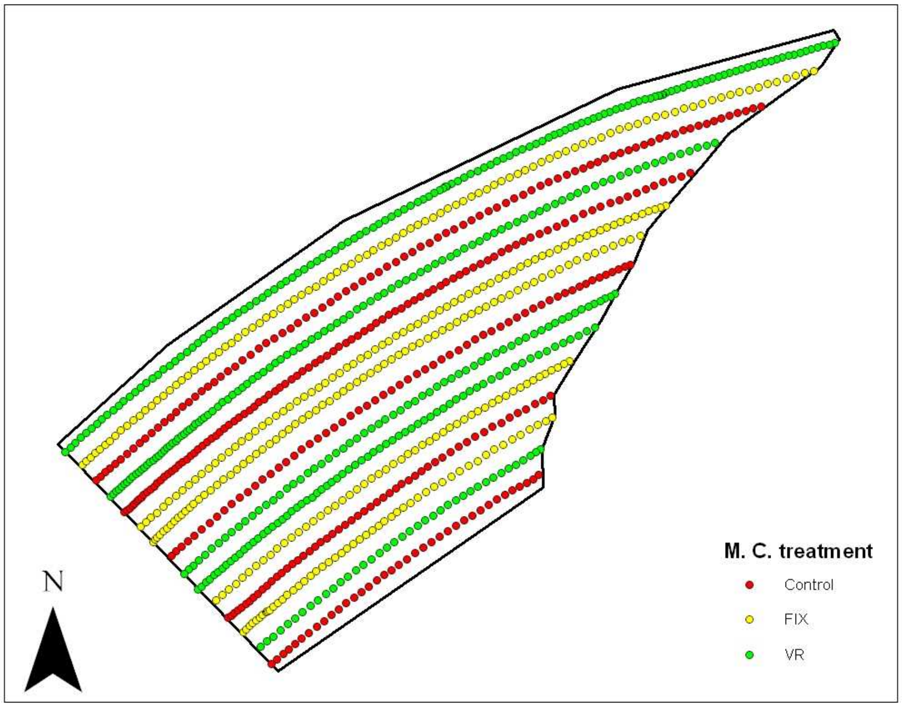

Figure 2. Experimental layout in the field

A plot of plant height from different dates shows the performance of the system (figure 3). 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 repeats throughout the image.

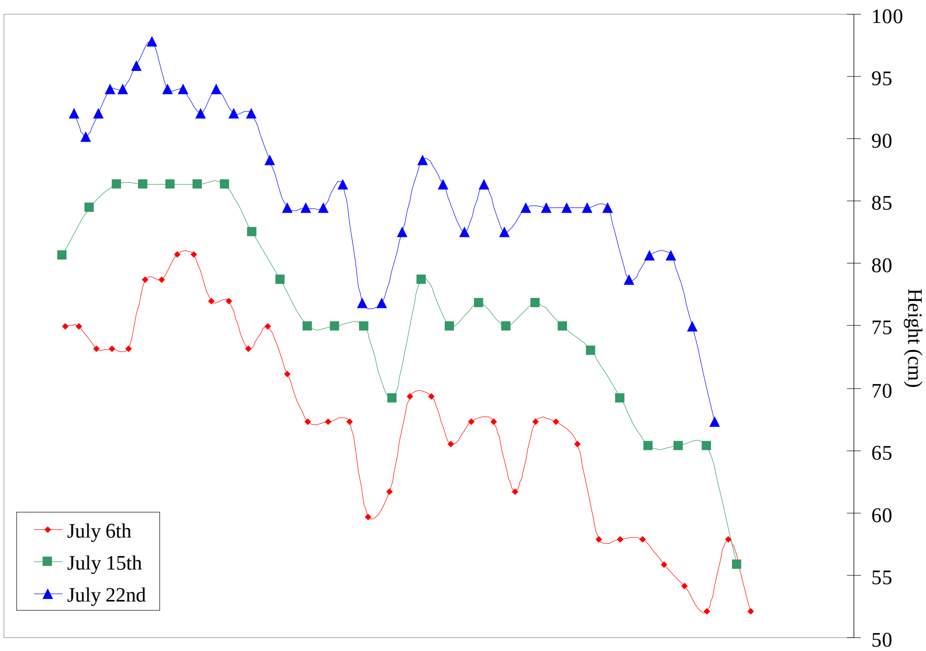

Figure 3. Plant height profile on different dates

When the system is passed over the same area in both directions and at two speeds 1.34 and 2.68 m/s (3 and 6 mph), one can see that the system is consistent, except for one of the passes, where the data seems to be skewed. The VCD that processes the histograms sent by the mini-array also has other tasks, such as acquiring the GPS position, the rates applied by the Raven and the historical data. The processor within the VCD is nearly used to its maximum; therefore it is possible that some of the height data points, due to an overload on the VCD are attributed to an incorrect position, caused by delay in processing.

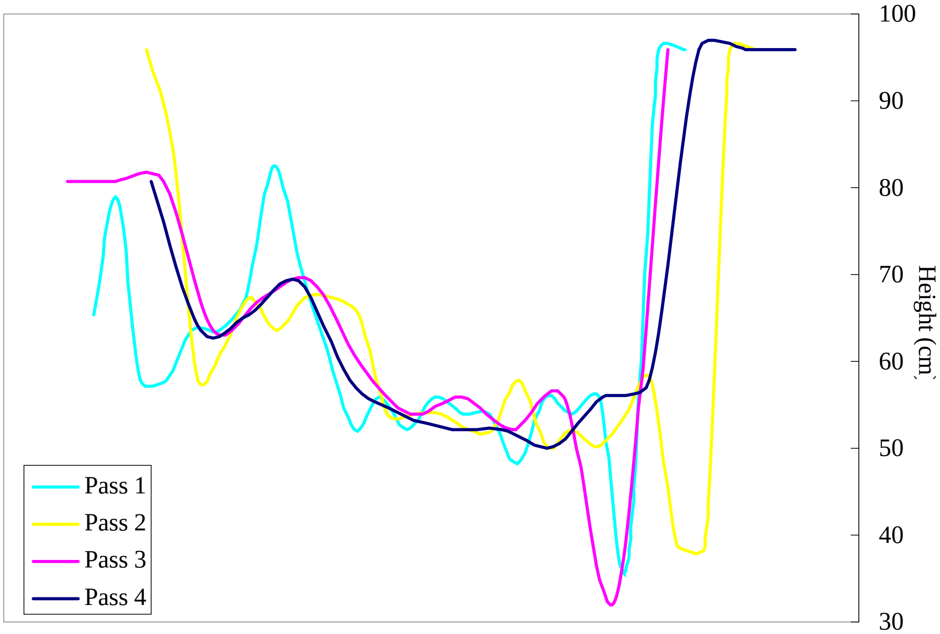

Figure 4. Four passes on the same area

One can see that 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. These points occur for only one second and don't have a significant impact on the mepiquat chloride application rate. Hardware and software improvements are needed to eliminate these zero height points.

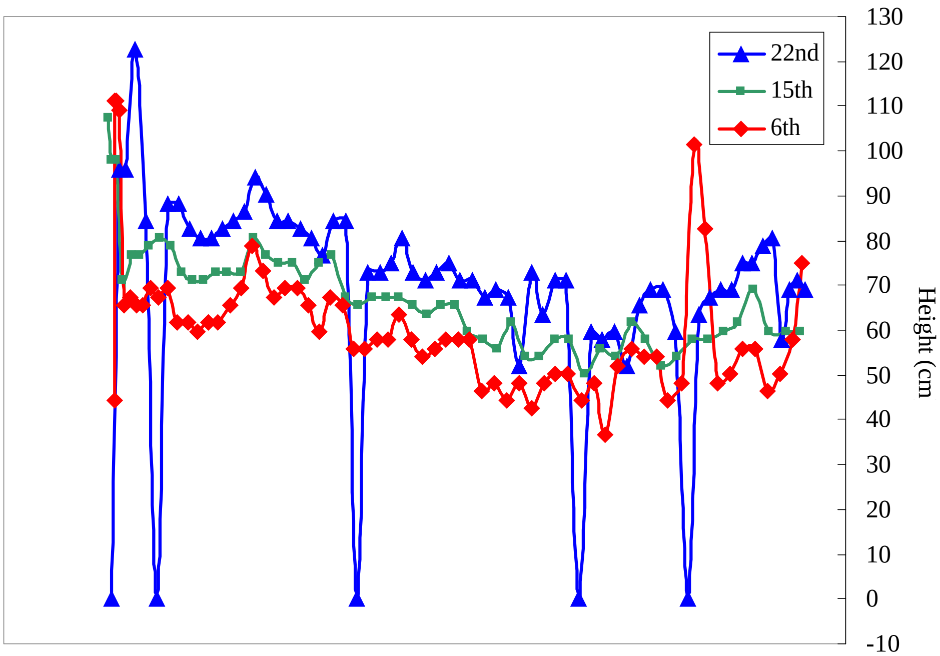

Figure 5. Plant height profile on different dates with some bad data

A plot of rate of growth and applied rate throughout the sprayer pass is show on figure 6. It is interesting to note that on the first portion of the graphic, even though the calculated rate of growth is not correct, possibly due to a problem in reading the historical data, the application rate follows the trend very well. This data pointed out the need to modify the rate algorithm to include a maximum allowable rate to handle situations where the historical data is missing. For the second part of the graph, when the rate of growth is low, the system tries to shutoff, but it can't. There is a delay between the change of rate of growth and change on the application rate, which is caused by the lag of time of when the VCD outputs the rate and the effective rate is applied by the controller.

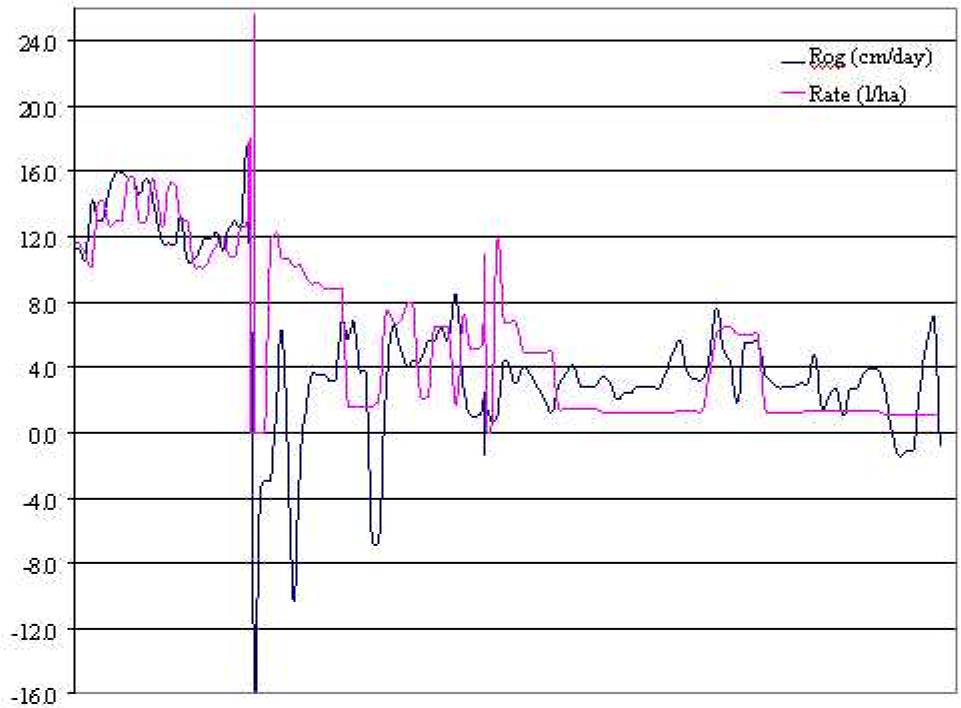

Figure 5. Plant height and application rate on a pass with some incorrect data

The average height for every replication for each one of the dates was used to on an ANOVA to check that there were significant increases in measured height within date. One can see that there is an effect for date with alpha=0.01.

Table 4. 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
Rep.	4	1610.56	402.64	10.94	<.0001
Date	2	2558.80	1279.40	34.77	<.0001
Error	36	1324.72	36.80		
Corrected Total	44	5517.84			

The means were than compared by Tukey's test to determine which dates had different heights. It can be seen that average heights are significantly different.

Table 5. Tukey grouping for average height (cm) within date (alpha =0.1)

Tukey Group	Mean	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

The ANOVA table for the RoG with the data subset by mepiquat chloride treatment and height class shows us that there is no significant effect of date or simply height class on RoG. It also shows that there is a significant effect with alpha=0.1 for mepiquat treatment and all the interactions.

Table 6. Unbalanced ANOVA for RoG

Combined	D.F.	Type III SS	Mean Square	F-Value	Pr > F
Date	1	1.54	1.54	0.45	0.5037
M.C. Treat	2	57.46	28.73	8.33	0.0003*
HgtClass	2	10.09	5.05	1.46	0.2316
Date*M.C. Treat	2	46.24	23.12	6.71	0.0013*
Date*HgtClass	2	74.10	37.05	10.75	<.0001*
M.C. Treat*HgtClass	4	27.63	6.91	2.00	0.0917*
Date*M.C. Treat*HgtClass	4	47.16	11.79	3.42	0.0086*
Error	1589	5478.56	3.45		
Corrected Total	1606	5725.67			

Considering the whole dataset it is interesting to note that there is significant difference between mepiquat chloride treatments between the control and variable rate, with alpha = 0.1.

Table 7. Unbalanced Tukey's test for treatment

Combined M.C. Treat	Diff. Between Means
Control - Fix	0.2226
Control - VR	0.4380***
Fix - VR	0.2154

Comparisons significant at the 0.1 level are indicated by ***

According to Tukey's test, there was no significant difference in rate of growth between the two dataset (July 22nd – July 15th and July 15th – July 6th). Height class was not significantly different either, considering both datasets together.

Considering the first dataset, which uses the Rog from July 15th – July 6th, there was no significant effect of mepiquat treatment, but there was for height class. The taller plants were significantly different than the medium and short plants, according to Tukey's Studentized range test.

Table 7. Unbalanced ANOVA for Rog July 15th – July 6th

July 15 - July 6	D.F.	Type III SS	Mean Square	F-Value	Pr > F
M.C. Treat	2	0.50	0.25	0.1	0.9013
HgtClass	2	15.23	7.61	3.19	0.0418*
M.C. Treat*HgtClass	4	6.31	1.58	0.66	0.6197
Error	794	1896.05	2.39		
Corrected Total	802	1918.33			

For the second date of the RoG (July 22nd –July 15th), the ANOVA table shows that there was a significant effect, with alpha = 0.01, for mepiquat treatment, height class and the interaction between the factors.

Table 8. Unbalanced ANOVA for Rog July 22nd – July 15th

July 22-15	D.F.	Type III SS	Mean Square	F-Value	Pr > F
M.C. Treat	2	103.29	51.64	11.46	<.0001*
HgtClass	2	69.00	34.50	7.66	0.0005*
M.C. Treat*HgtClass	4	68.52	17.13	3.80	0.0045*
Error	795	3582.52	4.51		
Corrected Total	803	3807.33			

Tukey's Studentized range test was used for comparison of unbalanced means, and for this second RoG, there was significant difference between mepiquat treatments and between height classes.

Tables 9 and 10. Unbalanced Tukey's Studentized Range test for mepiquat treatment and height class

M.C. Treat	Difference Between Means	HgtClass	Difference Between Means
Control - Fix	0.3669	Short - Medium	0.1483
Control - VR	0.8044 ***	Short - Tall	0.7089 ***
Fix - VR	0.4375 ***	Medium - Tall	0.5606 ***

Comparisons significant at the 0.1 level are indicated by ***

Even though mepiquat chloride was applied much later than desired (plants were near cutout), it is interesting to note that the plants were still growing in height and there was an effect of the product. For July 15th, there had not been enough time for the product to act on the plant, as it is known that the effects are seen best 12-15 days after application. On July 22, not only there was effect of mepiquat chloride, but also the rate of growth was lower for the areas where mepiquat chloride was applied in real time variable rate.

Conclusions

The variable rate application of mepiquat chloride based on continuously measured rate of growth is viable and promising in its results. There were statistical differences between the rate of growth in the variable rate area as compared to the fixed rate and control. This result was surprising, considering the lateness of the mepiquat chloride applications. When weather permits field operations at the appropriate times, a greater impact can be expected.

The HMAP-RoG system operated well and generally applied the desired application rates. It still needs some improvement in both hardware and software. The system is data intensive, with 200 Hz scanning rate of the height sensor, historical height and position data all being used in calculations of the application rate. Additional filtering of both rate of growth and mepiquat chloride application rates is needed to optimize performance.

References

Beck, A.D. 2001. *Real-time variable rate Pix® application system using a plant height sensor*. M.S. thesis, Texas A&M University, College Station, Texas.

Biles, S.P., and J.T. Cothren. 2001. Flowering and yield response of cotton to application of mepiquat chloride and PGR-IV. *Crop Science*. Crop Science Society of America,Madison, USA: 2001. 41: 6, 1834-1837. 34 ref.

Bourland, F.M., D.M. Oosterhuis, and N.P. Tugwell. 1992. Concept for monitoring the growth and development of cotton plants using main-stem node counts. *Journal of Production Agriculture. 1992. 5: 4, 532-538.*

Cothren, J.T. 1979. "Pix" - a cotton growth regulant. *Arkansas Farm Research. 1979. 28: 4, 5.*

Cothren, J.T. and D.M. Oosterhuis. 1993. Physiological impact of plant growth regulators. *1993 Beltwide Cotton Conferences.* 128-132.

Geiger, D.W. 2004. *Extending the utility of machine based height sensors to spatially monitor cotton growth.* M.S. Thesis Texas A&M University, May 2004.

Kennedy, C. W., and R.L. Hutchinson. 2001. Cotton growth and development under different tillage systems. *Crop Science*. Crop Science Society of America, Madison, USA: 2001. 41: 4, 1162-1168. 23 ref.

Kerby, T. A. 1985. Cotton response to mepiquat chloride. *Agronomy Journal. 1985. 77: 4, 515-518. 22 ref.*

Kerby, T.A., K. Hake, and M. Keeley. 1986. Cotton fruiting modification with mepiquat chloride. *Agronomy Journal*. 1986. 78: 5, 907-912. 13 ref.

Kerby, T.A., R.E. Plant, and R.D. Horrocks. 1997. Height-to-node ratio as an index of early season cotton growth. *J. Production Agriculture* 10(1):80-83.

Landivar, J. A. 1998. The MEPRT method to determine time and rate of mepiquat chloride applications: uses and misuses. *1998 Proceedings Beltwide Cotton Conferences, San Diego, California, USA, 5-9 January 1998. Volume 2. National Cotton Council,Memphis, USA: 1998. 1414-1416. 4 ref.*

Landivar, J.A., J.T. Cothren, and S. Livingston. 1996. Development and evaluation of the average five internode length technique to determine time of mepiquat chloride application. *1996 Proceedings Beltwide Cotton Conferences*, Nashville, TN, USA, January 9-12, 1996: Volume 2. National Cotton Council,Memphis, USA: 1996. 1153-1156. 1 ref.

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. *1995 Proceedings Beltwide Cotton Conferences*, San Antonio, TX, USA, January 4-7, 1995: Volume 2.. National Cotton Council,Memphis, USA: 1995. 1081-1085. 5 ref.

Munier, D.J., B.L. Weir, S.D. Wright, and T.A. Kerby. 1993. Applying Pix at variable rates when plant height varies in a cotton field. *Proceedings, Beltwide Cotton Conferences, 10-14 January 1993, New Orleans, Louisiana, USA.. National Cotton Council,Memphis, USA: 1993. 1208-1209. 2 ref.*

Reddy, V.R., A. Trent, and B. Acock. 1992. Mepiquat chloride and irrigation versus cotton growth and development. *Agronomy Journal.* 1992. 84: 6, 930-933. 23 ref.

Searcy, S.W., and A.D. Beck. 2000. Real-time assessment of cotton plant height. *Proc. Fifth Intl. Conf. on Precision Agriculture*, 1-13. Madison, Wis.: ASA, CSSA, SSSA.

Siddique, M.R.B., M. Prasad, and R.C. Gautam. 2002. Response of cotton (Gossypium hirsutum) to mepiquat chloride and topping under varying levels of nitrogen. *Indian Journal of Agronomy*. Indian Society of Agronomy,New Delhi, India: 2002. 47: 4, 550-555. 9 ref.

Stewart, A.M., K.L. Edmisten, R. Wells, D.L. Jordan, and A.C. York. 2001. Wick applicator for applying mepiquat chloride on cotton: I. Rate response of wick and spray delivery systems. *Journal of Cotton Science*. National Cotton Council, Memphis, USA: 2001. 5: 1, 9-14. 14 ref.

Stewart, A.M., K.L. Edmisten, R. Wells, A.C. York, and D.L. Jordan. 2001. Wick applicator for applying mepiquat chloride on cotton: II. Use in existing mepiquat chloride management strategies. *Journal of Cotton Science.* National Cotton Council, Memphis, USA: 2001. 5: 1, 15-21. 16 ref.

Thurman, M.E., and R.W. Heiniger. 1998. Using GPS to scout cotton for variable rate Pix (mepiquat chloride) application. *Proceedings of the Fourth International Conference on Precision Agriculture, St. Paul, Minnesota, USA, 19-22 July 1998. American Society of Agronomy,Madison, USA: 1999. 953-961. 11 ref.*