ON-THE-GO SENSOR TECHNOLOGY FOR COTTON MANAGEMENT

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CHAPTER I

INTRODUCTION

The United States of America is the third largest producer of cotton in the world. Average cotton production in the US for the last five years was found to be approximately 4.6 million metric tons (4.6 X 10^9 kg) harvested from nearly 4.8 million hectares (4.8 X 10^4 km^2; USDA, 2008; Appendix B). Upland and American Pima are two major varieties of cotton found in the US. Upland cotton holds more than 97% share of total cotton production in US (Appendix B). It was found from eight years data (from 1999-2006) that total gross value of production for cotton was nearly $394 per acre (approximately $9.7 X 10^3 / km^2; National Cotton Council of America). Cost of production depends upon management practices used for the cotton crop. Selection of seeds and variety, water and irrigation management, weed management, insect management, use of fertilizers, plant growth regulators, and defoliation are the most commonly used management practices. Defoliation involves application of chemicals known as defoliants, just before harvesting. These chemicals cause shedding of leaves thus making harvesting easier.

Cotton is a unique plant with aggressive growth habits. Plant growth regulators (PGR) are the chemicals used to re-channel the plant nutrients to increase the reproductive growth by decreasing the vegetative growth at the same time. Excessive vegetative growth can cause many problems such as boll rot, fruit abscission, and low overall yield. Most commonly used PGR is Mapiquat chloride (available under trade name Pix) applied by blanket method in which same quantity of chemical is sprayed throughout the field. Uniform quantity of chemicals through out the field may lead to under or over application at some of the places within the field, resulting low yield and many other problems. Variable rate technology can be the solution for such problems. In addition, it reduces the total chemical used hence reduces the overall cost of cotton production.

There are a number of recommendations available related to the rate of mepiquat chloride to be used on the basis of plant growth status, for example plant height, height to node ratio, number of nodes etc. In several studies, remote sensing using satellites and aerial imagery have been used to make the vegetative indices maps for different cotton fields. These maps are then used to find the correlation between cotton growth status and different vegetative indices. This is an indirect method of measuring cotton structural parameters or crop structural indices to predict recommendations for application of PGRs and defoliants.

Remote sensing using aerial imagery and satellites is weather dependent, involves a large amount of time and labor. In addition, these techniques cannot be used to make a real time applicator for PGRs and defoliants. In-field observation of these crop structural parameters for on-the-spot decision making for variable rate application of growth regulators and defoliants is still not completely possible. Through this research, the efforts have been made to measure cotton structural parameters indirectly by recording the normalized difference vegetative index (NDVI) and height of cotton using on-the-go sensor technology. If successful this research could become a base for an automatic real time variable rate sprayer for the application of plant growth regulators taking into account spatial growth variability.

CHAPTER II

LITERATURE REVIEW

Cotton is unique and acts both as a pseudo-annual and perennial plant. It has aggressive growth habits, which depend upon water and nutrient uptake. It has been found that the maximum height a cotton plant can reach up to is seven feet. For cotton, vegetative and reproductive growth occurs simultaneously and a little imbalance in the nutrient uptake results in more vegetative growth. Although vegetative growth is necessary to support reproductive growth, excessive vegetative growth may lead to many problems such as shading of lower canopy results in early fruit abscission developed at the base of the plant (Ooeterhuis, 2001). Also due to the more humid microenvironment present at the shaded portion under the canopy, boll rot increases in that area (Eaton and Ergle, 1954). Fruits start growing at higher nodes to compensate the early fruit abscission (Silvertooth et al., 1999). Also it is seen that shaded areas of plants are more prone to attack of insect. Fruits developed in compensatory zone do not belong to main fruiting zone hence become small in size, resulting in lower overall yield (Jones & Wells, 1998). Compensation given to the plants having early fruit abscission, to acquire high yield, results in delayed maturity (Silvertooth et al., 1999).

Cotton plants can self generate many hormones such as gibberellins, ctoksins and auxins which regulate the vegetative and reproductive growth of different parts in a plant. Man made chemical growth regulators are used to control production of these hormones to get profitable and desired growth in cotton. Mepiquat chloride, a common and world wide accepted growth regulator, is used to control gibberellins hormone to decrease vegetative growth in a cotton plant. Plant growth regulators (PGRs) are used to retard vegetative growth by redirecting nutrients to cause reproductive growth. Redirecting nutrients increases lint yield by increasing boll production (Bethel et al., 2003). Also harvesting of a smaller plant with less vegetative growth is much easier than harvesting the taller plant with more vegetative growth (Stewart, 2005). Another important cotton management practice performed just before the harvesting is defoliation, which is performed by applying chemicals, known as defoliants. These chemicals cause plant leaves to fall-off timelier than the natural process of abscission and senescence in cotton crop (Cothren et al., 2001) thus make harvesting easier.

Typically PGRs and defoliants are applied uniformly. One of the most commonly used methods for application of PGR and defoliants is uniform application method (also known as the blanket method). In this method chemicals are applied at constant rates throughout the field, which may result in over and under application at few locations with in the field (Fridgen et al., 2003). Over or under application of PGR results in low yield, whereas uniformly grown cotton reduces insect infestation and harvesting problems (Cothren et al., 1993). Timing and recommendations for uniform PGR application are determined by cotton structural parameters like height, height-to-node ratio (HNR), average length of top five internodes, and inter-nodal length (Kerby et al., 1990). Structural parameters like percent open bolls and nodes above the cracked bolls (NACB) are used for determining the rate of defolian (Brecke et al., 2001). These parameters are also known as crop structural indices. Recording crop structural indices is known as plant mapping (Jenkins and McCarty, 1995). Other structural indices that are being used for cotton crop mapping are fruit retention (FR), growth rate (GR), nodes above white flower (NAWF) and main stem node number (MSN) (Kerby et al., 1997; Kerby et al., 1998; Bourland et al., 1992).

Several studies have been conducted to measure cotton physiological parameters indirectly and to define cotton growth status at different growth stages to predict recommendations for growth regulators and defoliants. Different methods that have been used to measure growth parameters are remote sensing using aircrafts and satellites, in-field machine vision, and by manually taking samples from different sites (Reddy et al, 2003; Plant et al, 2000; Goel et al, 2003; Kataoka et al., 2003; Jenkins and McCarty, 1995). Reflectance data collected in the visible, infrared, and microwave regions are correlated with physically measured cotton growth and structural indices (Tucker, 1979; Wanjura and Hatfield, 1987). Different studies have shown correlations between remotely sensed reflectance data and cotton growth parameters and yield (Yang, 2001; Mass, 1998; Yang, 2004; Leon et al., 2003.; Bethel et al.,2003).

Researchers have also used hyperspectral and multi-spectral reflectance data of crop canopy to measure yield and plant growth physiological parameters (Zarco-Tejada et al., 2005; Plant et al., 2000, Harris et al.,2004). It was observed that cotton growth status can be predicted accurately using the ratio of reflectance data in green and red region (Wanjura and Hatfield, 1987). Cotton yield was found to be related with mid-season reflectance data (Vellidis et al., 2004). Lint yield was found correlated with red and green bands but poor correlation was observed with near infrared reflectance data recorded using multi-spectral imagery (Yang et al., 2001). In another study it was observed that reflectance data for near infrared region can be used to predict plant vigor for cotton crop (Li et al.,2001).

The reflectance data is generally expressed in terms of indices, which are calculated by mathematical relations of crop reflectance measured in different wavelength bands. Most of the indices are relations of reflectance data recorded in red (roughly 600-700 nm) and near infrared (roughly 700-900 nm) or green (roughly 500-600 nm) spectral bands (Perry and Lautenshlager, 1984) also known as vegetative indices. Some of these vegetative indices are Normalized Difference Vegetative Index (NDVI), Nitrogen Vegetation Index (NVI) (Takebo et al.,1990), Green Vegetation Index (GVI), Visible Atmospherically Resistant Index (VARI) (Haris et al. , 2004), Green Normalized Difference Vegetative Index (GNDVI) (Earnest and Varco , 2005), Ratio Vegetation Index (RVI), Difference Vegetative Index (DVI) (Leon et al., , 2003), Relative Nitrogen Vegetation Index (RNVI) (Plant et al., 2000), Soil Adjusted Vegetation Index (SAVI) (Huete, 1988), Modified Soil Adjusted Vegetative Index (MSAVI), Transformed Soil Adjusted Vegetation Index (TSAVI) (Qi et al., 1994), Renormalized Difference Vegetative Index (RDVI), Weighted Difference Vegetation Index (WDVI) (Roujean and Breon, 1995), Infrared Percentage Vegetation Index (IPVI) (Crippen, 1990), and Transformed Vegetation Index (TVI) (Payero et al., 2004). It has been observed in different studies that different vegetative indices can be correlated with different crop structural parameters; therefore recording such vegetative indices can be the indirect method of measuring crop structural indices.

Cotton plant height was found to be significantly correlated with many vegetative indices (R^2 >0.65) such as NDVI, RVI and DVI (Leon et al., 2003). Linear or logarithmic relationships were also observed with plant height (R^2=0.63) and main stem nodes (R^2=0.67) when correlated with Simple Ratio (SR) which is ratio of reflectance in red and near infrared region (Reddy et al., 2003). Also correlation (R^2 =0.64) was observed between lint yield and NDVI at first flower stage. In another study, cotton plant height has been correlated to GNDVI (Earnest and Varco 2005). Cotton maturity parameters were found to be closely correlated with GVI and Visible Atmospherically Resistant Index (VARI) (Harris et al., 2004). Out of the many vegetative indices that exist, the most common and highly correlated index is NDVI (Tucker, 1979; Plant et al., 2000). Many studies have shown strong correlations between NDVI and different growth parameters for cotton crop(Kirkpatrick et al., 2005, Goel et al., 2003, Reddy et al., 2003). In addition to NDVI and plant height, strong correlations have also been observed between NDVI and height of top five nodes in cotton plant (Kirkpatrick et al., 2005).

Airborne and field hyperspectral remote sensing has also been used to estimate crop biophysical parameters for corn. A high correlation has been indicated between crop physical parameters such as LAI, leaf chlorophyll content, leaf nitrogen content and plant height with the reflectance data (Goel et al., 2003). Results were improved (R^2=0.90) when NDVI was used instead of five-wavelength reflectance values. Exponential positive relationships have been observed between NDVI and LAI (R^2=0.67), NDVI and above ground biomass (R^2=0.69), and NDVI and lint yield (R^2=0.64) for cotton using hyper spectral data. In another study on cotton conducted in 1997, 1998 & 2005 using remote sensing at six different farms in North Carolina, consistent correlations (R^2= 0.50) were observed between NDVI and plant height for all sites and all years, but no significant relationship was observed out for other cotton growth parameters (Nelson 2006). Read et al. (2003) also found height, leaf area index and lint yield of dryland cotton closely related with NDVI maps and NIR band values obtained from multispectral imagery and radiometer data for the month of July for peak bloom. Thus, it can be inferred that NDVI can be used to measure the physiological parameters of cotton for defining growth status of a plant.

Plant et al., (2000) used aerial photography to make NDVI maps for Acala cotton California and found strong correlation between NDVI and nodes above cracked boll (NACB) ($R^2 > 0.80$). Also R^2=0.51-0.65 was observed between NDVI and nodes above white flower (NAWF) for different growth stages. Another important structural parameter is plant height, which is considered as an important deciding factor for PGR application (Kerby et al. 1990). Munier et al. (1993) related plant height with plant vigor and early fruit retention, and considered plant height as a good indicator for use of PGRs. In a study conducted in northwest region of Mississippi, NDVI and GNDVI maps were generated using multispectral imagery and found to be correlated with different cotton structural parameters. Cotton height was found to be correlated with NDVI (R^2=0.73) and GNDVI (R^2=0.72) for the data of first week of September 2002. Another growth parameter known as percentage open bolls showed negative correlation with NDVI and GNDVI whereas nodes above the cracked bolls (NACB) showed positive correlation with NDVI and GNDVI (Fridgen et al., 2003). In 2003, a study conducted at Perthshrine farms near Gunnison, Mississippi, multi-spectral data was collected with an airborne platform. The vegetative indices obtained from multi-spectral data showed correlations with cotton structural parameters. R^2= 0.47 was observed between cotton height and TSAVI, and R^2= 0.55 was obtained between cotton height and NDVI. Length of top five nodes was also correlated with NDVI (R^2= 0.36), GNDVI (R^2=0.40) and transformed soil adjusted vegetative index (TSAVI) (Lewis et al., 2003).

Variable rate application, which has also been introduced for the application of PGR and defoliant, make use of remote sensing, aerial imagery and in-field machine vision (Lewis et al., 2003, Bethel et al., 2003). In this method site specific treatments were applied based upon the maps of different vegetative indices acquired by remote sensing (Lewis et al., 2003 Bethel et al., 2003, Fridgen et al., 2003). The variable rate application of PGR and defoliants is an economical method as compared to traditional uniform application. In a study conducted near Lemoore, California the chemical use was reduced by 12% for variable rate PGR application over traditional uniform application for the use of PGR (Bethel et al., 2003). In another study conducted in Mississippi in the delta region, variable rate application reduced the use of defoliants by 17-18% when compared to traditional uniform application method (Fridgen et al. 2003).

Variable rate application using satellite or airborne images has many advantages and disadvantages. Cloudy conditions greatly affects the NIR or visible data (Barnes, 2004). Moreover all these techniques are either costly, weather dependent, time consuming or requires lab work to process images before it can be used for making cotton management decisions. In addition, there is a need of independent, easily affordable technique, which requires no lab work and can be used anytime in the field irrespective of cloudy conditions. System containing on-the-go sensors that can work in real time could be a solution to all of these problems. With such type of system, time could be saved which otherwise would be spent in interpreting data and generating application maps (Barnes, 2004). It has been proved in another study conducted at

Tennessee, that on-the-go NDVI sensors (GreenSeekers®) could be a substitute for aircraft based multispectral imagery (Sharp et al., 2004). A similar type of on-the-go sensor system for variable-rate nitrogen fertilizer application has already been developed and tested for wheat and corn. In this system, NDVI sensors were used to calculate yield potential for every 0.40 m^2 area with in the field. It could also apply required amount fertilizer for the same amount of area to achieve desired yield potential all in real time. This sensor system uses the correlation between the crop yield and NDVI of the plants (Solie et al., 2002).

2.1 Research Objectives

Variable rate technology that has been very successful for wheat and corn using on-the-go sensor technology has never been tested for cotton crop. Literature shows that more work is required for cotton. Therefore, the objective of this study was to evaluate on-the-go sensor technology for defining different cotton structural parameters as function of NDVI and plant height with the desire to construct a real-time plant growth regulator applicator in future. In detail, the objectives of this study are:

1) To evaluate on-the-go ultrasonic sensors for the use of measuring cotton height
2) To define manually measured plant height (H_m) and height to node ratio (HNR) as a function of NDVI and plant height, which can be used to construct real-time plant growth regulator applicator in future.

CHAPTER III

MATERIALS AND METHODS

3.1 Construction of sensor system

A sensor system was assembled using seven NDVI sensors (GreenSeeker®, N-Tech Industries, Ukiah, CA; Appendix A), two ultrasonic distance sensors (MassaSonic™ M 5000, Massa Product Corporation, Hingham, MA), a rotary potentiometer boom height sensor (10K Linear, 5 turns , Allen Bradley Company, EI Paso, TX), Differential global postioning system (Trimble, AgGPS 132, Trimble Navigation Limited Sunnyvale, CA) and a radar ground speed sensor (Dickey John Radar III, DICKEY-john Corporation, Auburn, IL). Figure 1 shows radar ground speed sensor mounted on the spot sprayer.

Figure 1. Radar ground speed sensor mounted on the spot sprayer

Data from these sensors were recorded with a SOMAT eDaq data logger (SoMaT Corporation, 702 W.Killarney St, Urbana, IL 61801, USA) (Figure 2). Output from the GreenSeeker® sensors and the GPS were in the form of control area network (CAN) signals therefore they were connected to the vehicle bus input of the eDaq through CAN bus. The analog voltage signals from the ultrasonic sensors and potentiometer height sensor were logged directly with the eDaq data logger using “High level input channels” or voltage input channels. The digital pulse signal from ground speed sensor was connected to pulse counter input of the eDaq (Appendix A). The data acquisition system was time triggered and had a sampling rate of 5 Hz. The data acquisition system and sensors were mounted on a small sprayer to create a mobile platform as shown in the Figure 3.

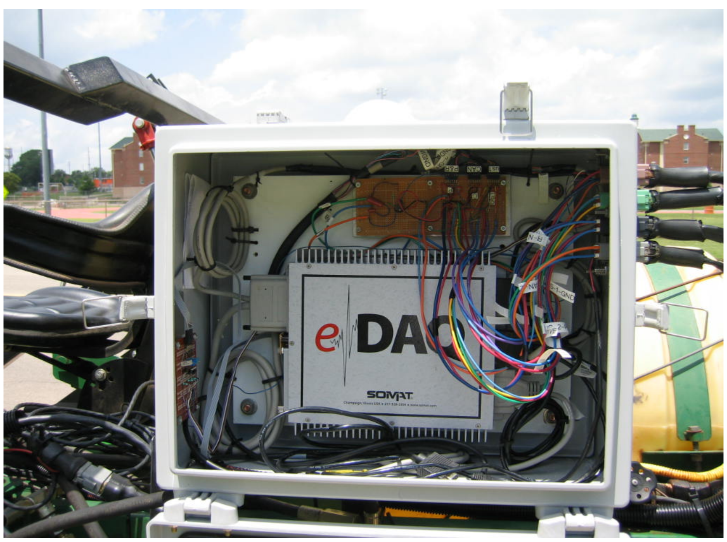

Figure 2. eDaq SOMAT data logger used to log data from different sensors

Figure 3. Sensors and data acquisition system installed on small spot sprayer

Seven GreenSeeker® sensors were configured such that four were mounted directly over the crop row and three were mounted between the crop rows (Figure 3). The ultrasonic sensors were positioned in front of the third and fifth sensors where there was a clear view of the canopy. As shown in Figure 4.

Figure 4. Ultrasonic sensor mounted in front of a GreenSeeker® sensor

The GreenSeeker® sensor outputs NDVI values. The ultrasonic sensors were calibrated to measure the distance between the canopy and the GreenSeeker® sensors (equation 1). In the rotary potentiometer boom height sensor (Figure 5) a small gear train was used to convert 70 degree boom arm angle to 5 turns of potentiometer and the sensor output voltage was calibrated for boom height with respect to ground surface (equation 2). The height of the crop was calculated by difference of these two heights (equation 3).

$$H_o = (0.0182 \times V_{US}) - 24.606 \tag{1}$$

where

H_o = Distance in inches of ultrasonic sensor from canopy

V_{US} = Output voltage in milli volts from an ultrasonic sensor

$$H_B = (0.0227 \times V_{PM}) + 11.176 \tag{2}$$

where

H_B = height of boom in inches

V_{PM} = output voltage in milli-volts of potentiometer boom height sensor

$$H_S = H_B - H_o \tag{3}$$

where

H_s = Height of the canopy from ground in inches

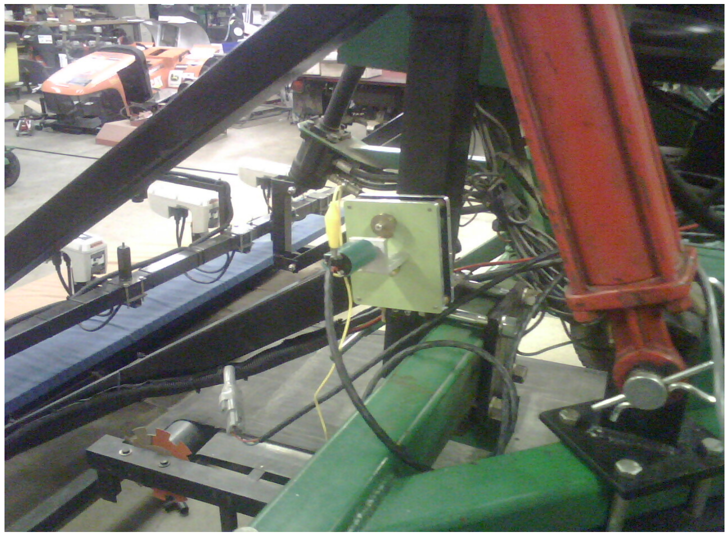

Figure 5. Potentiometer boom height sensor mounted at the side of the boom of spot sprayer

3.2 Data collection

Sensor data, NDVI over the row ($NDVI_{OR}$), NDVI between the row ($NDVI_{BR}$) and height of the plants were collected for a total of 72 plots from two different research studies near Altus, OK. A nitrogen rate (0, 40, 80, and 120 lbs N/ac) experiment study and a long term (30+ years) fertility study with random nitrogen rates were used to create growth differences for sensor measurement. Plots varied in length, but were at least four rows wide with 40 inch row spacing. Both studies were furrow irrigated (Table 1).

Sensor data were collected multiple times throughout the season (Table 2) as ground conditions permitted. Sensor data were collected by driving the spot sprayer through plots while logging data. The data were stored as SIF files which were then converted to Excel files using SoMat Infield software (SoMaT Corporation, 702 W.Killarney St, Urbana, IL 61801, USA). Also plant measurements were taken manually at five locations within each individual plot to coincide with sensor data collection. These measurements varied depending on the growth stage and included plant height, number of nodes, nodes above cracked ball (NACB), plot weight and seed count as shown in Table 3. The data were then compared for the dates for which both manual data and data measured by the sensors available. The data for July 30, 2007 was not compared because of error in the GPS data.

Table 1. Detailed information of the experimental studies

Name and location		
Name of study	Nitrogen rate study	Long term 30 yrs fertility Study
Location	Lon:-99.3355, Lat:34.5910	Lon:-99.3384, Lat:34.5929
Crop description		
Crop	Upland Cotton	Upland Cotton
Variety	ST 4554 B2F	PM 2280 BR
Planting date	5/18/2007	5/19/2007
Rate, Unit	52000 Plants/acre	15 pounds/acre
Site and Design		
No. of plots used	16	56
Plot width	13.33 feet	20 feet
Plot length	60 feet	55 feet
Row spacing	40 inches	40 inches
Replications	4	4
Study design	Completely Randomized Block Design	Completely Randomized Block Design
Treatments	0, 40, 80, and 120 lbs N/ac	Variable nitrogen rate

Table 2. Available data measured manually and measured using sensors for 2007 collected at Altus,OK

	Sensor data		Manual data	
Date/Study	Nitrogen rate study	Long term fertility study	Nitrogen rate study	Long term fertility study
July 10	x			
July 12		o	x	o
July 18	x	o	x	
July 30	x	o	x	o
August 9	x	o	x	o
August 13	x		x	
August 14	x			
August 22	x		x	
September 26	x	o	x	
Ocotober 24			x	

`

Table 3. Manually measured cotton structural parameters and plot measurements at different growth stages during the 2007 cotton season

			Manual data		
Date/Study	Days after planting	Growth stage	Nitrogen rate study	Long term fertility study	Type of manual measurement taken
May 18	0	Planting			
May 23	5	Emergence			
June 25	38	First Square			
July 10					
July 12			x	o	Manual height Number of nodes
July 16	59	First Flower			
July 18			x		Manual height Number of nodes
Aug. 9			x	o	Manual height Number of nodes
Aug. 13			x		Manual height Number of nodes
Aug. 22			x		Manual height Number of nodes
Sept. 11	116	Open Boll			
Sept. 26			x		Number of nodes NACB, %Open Bolls
Oct . 4	140	Harvest			
Oct . 24			x		Plot weight, Seed count

3.3 Data processing

Data processing was done in four stages; preprocessing, georeferencing, visual analysis and statistical analysis. First two stages were done in MATLAB (The MathWorks, Inc. 3 Apple Hill Drive Natick, MA 01760-2098 USA). Visual analysis (Appendix A) and statistical analysis were done in ArcView and JMP-7 (JMP® 7 Statistical Discovery Software SAS Institute Inc. SAS Campus Drive, Building S, Cary, NC, 27513) respectively. In preprocessing, the asynchronous data from all the sensors was averaged for the same values of longitude, which was changing with change in distance. New averaged values of heading, latitude, and longitude obtained from the GPS were used to geo-reference individual sensors and their corresponding measurements using a program developed in MATLAB (The MathWorks, Inc. 3 Apple Hill Drive Natick, MA 01760-2098 USA).

Thereafter the data from the individual GreenSeeker® (NTech Industries, Inc. 740 South State Street, Ukiah, CA 95482) sensors were coded, based on the sensor location relative to the row. The georeferenced data were then imported and plotted in ArcView GIS Software (ESRI 380 New York Street Redlands, CA 92373-8100, USA). The individual plots and their corresponding data were then extracted visually in ArcView for each field. The data were then labeled according to different plot numbers and treatments. The extracted data of each plot were averaged in MATLAB to yield single values for measured parameters for each plot. The average values of cotton physiological parameters were also calculated for each plot from manually measured data. Inaddition, weighted average (WA) and NDVI ratio was also calculated. NDVI ratio is the ratio of $NDVI_{BR}$ to $NDVI_{OR}$. WA is the weighted average of $NDVI_{OR}$ and $NDVI_{BR}$. The average values of both these terms were also used for analysis.

In the statistical analysis, sensed data was correlated with the manually measured cotton structural data for the time when there was a need to apply PGR. In our case it was month of July data. Therefore, the data was analyzed using multiple regression analysis in JMP-7 statistical software and the best fit models were found for both the nitrogen rate study and the long term fertility study. To find the best fit model, the standard least square and step-wise methods were used to define number of nodes and HNR as a function of $NDVI_{OR}$, $NDVI_{BR}$ and plant height. Also the correlation between the crop height and NDVI was analyzed.

CHAPTER IV

RESULTS AND DISCUSSION

4.1 Manually measured plant height Vs Plant height measured by sensors

Cotton height measured using ultrasonic sensors (H_s) was correlated with manually measured plant height (H_m) (Figure 6). The value of $R^2 = 0.80$ was observed between H_m and H_s for the accumulated data, i.e. collective data for all the dates for both experimental studies. A linear relationship was observed with slope equal to 1.04 and intercept of -6.34. The intercept was a bias in the cotton height measured by the sensors, which was close to the average height of furrow. This bias was observed because H_m was measured from cotyledons to the top-most point of the upper node of cotton plant, whereas H_s was measured with respect to the ground surface on which tires of the spot sprayer were moving (Figure 7).

Much better relation was expected between H_m and H_s. The bias in H_s and variation in the height of cotyledons could be the reasons for lower value of R^2. Regression analysis for individual sampling dates for both the studies was also done between H_m and H_s. No relation between the two heights was observed for the nitrogen rate study for all individual sampling dates except July 18 ($R^2 = 0.19$). However, data from long term fertility study showed better relationship between H_m and H_s (Table 4).

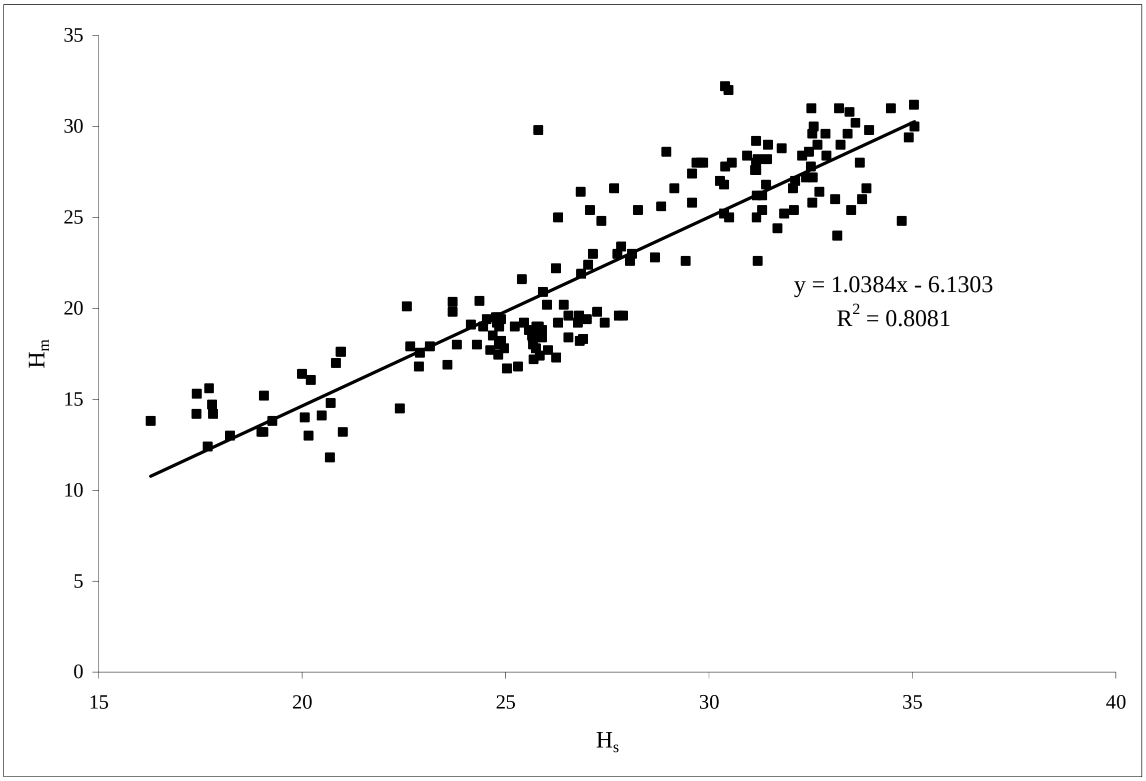

Figure 6. Relationship between manually measured plant height (H_m) and plant height measured by sensors (H_s)

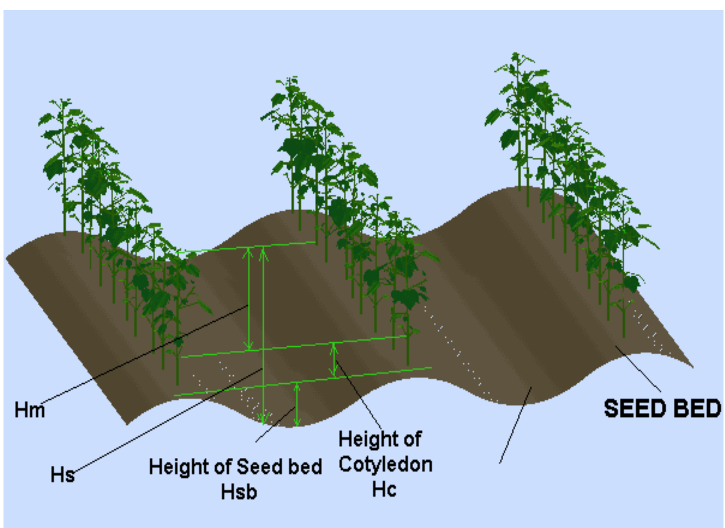

Figure 7. Diagram showing the bias in the measurement of height of crop by sensors.

Table 4. Results obtained from regression analysis between H_s and H_m for individual sampling dates

Date	Coefficient of determination (R^2)
Nitrogen rate study	
July 10	0.08
July 18	0.19
August 9	0.003
August 13	0.07
August 22	0.07
Long term fertility study	
July 12	0.38
August 9	0.55

To determine the reasons for the low values of R^2 observed between H_s and H_m an additional analysis was performed. Four plots,for which the complete height data set was available, were taken from the nitrogen rate study . The data set constituted the data for height from cotyledons to the top of the plant (H_m), height of cotyledons (H_c) and height of seedbed (H_{sb}). The pooled t-test was applied to evaluate if both, H_m and H_s were significantly different. Table 5 shows the results obtained from the analysis.

Table 5. Results obtained from pooled t-test* applied on H_s and H_m

Plot No.	Average H_s	Average H_m	P value
401	27.2 inches	19.6 inches	< 0.01
402	27.4 inches	19.2 inches	< 0.01
403	24.9 inches	19.0 inches	0.08
404	25.8 inches	19.0 inches	< 0.01

*alpha=0.05

The results indicated that H_m and H_s were significantly different for three out of four plots. It means H_s and H_m are not comparable. This could be the reason for lower values of R^2 obtained for individual sampling dates. Further, H_c and H_{sb} were added to H_m to get the total height of cotton plant. The pooled t-test was applied to evaluate if the manually measured total plant height (H_m+H_c+H_{sb}) and H_s were significantly different. The p-values greater than 0.05 indicated that manually measured total plant height and H_s were not significantly different. Hence, the plant heights measured manually and by sensors are comparable (Table 6). Based on the results obtained it was concluded that the ultrasonic sensors could be used to measure crop height.

Table 6. Results obtained from pooled t-test applied on H_s and total height of the cotton from the ground

Plot No.	Average H_s	Average (H_m +H_c+H_{sb})	p value
401	27.2 inches	27.40 inches	0.89
402	27.4 inches	26.90 inches	0.56
403	24.9 inches	26.80 inches	0.55
404	25.8 inches	26.90 inches	0.47

*alpha=0.05

4.2 Measurement of cotton structural parameters for the application of plant growth regulators

Regression analysis was carried out between the cotton structural parameters, which are important for PGR recommendations, and the data measured by sensors ($NDVI_{OR}$, $NDVI_{BR}$ and H_s). Table 7 and 8 show the regression analysis results obtained for the nitrogen rate study and the long term fertility study, respectively. The data was recorded from the month of July (considered as important time for PGR application) to the end of August. It was observed that the value of R^2 between H_m and $NDVI_{OR}$,for the nitrogen rate study was 0.15 on July 10, and 0.48 on July 18 (Table 7). The possible reason for increase in the value of R^2 could be the increase in vegetative growth in cotton between July 10 and July 18. More vegetative growth means more canopy coverage, which results in more $NDVI_{OR}$. It was observed that for the corresponding period, the average value of

$NDVI_{OR}$ had increased from 0.67 on July 10 to 0.76 on July 18 (Table 9) . In addition, increase in the height of the crop was noticed (Table 9). The increase in $NDVI_{OR}$ and height of the crop during this period indicated increase in vegetative growth. This resulted in a better relationship between H_m and $NDVI_{OR}$ for July 18, as compared to July 10.

Table 7. R^2 values between parameters measured manually and measured using on-the-go sensor system for individual sampling dates for the nitrogen rate study

	Nitrogen Rate Study				
	July 10	July 18	August 9	August 13	August 22
			$NDVI_{OR}$		
H_m	0.15	0.48	0.01	0.04	0.004
Number of Nodes	0.28	0.001	0.001	0.001	0.015
HNR	0.01	0.22	0.09	0.019	0.027
			$NDVI_{BR}$		
H_m	0.01	0.37	0.0004	0.2	0.035
Number of Nodes	0.01	0.02	0.04	0.09	0.02
HNR	0.001	0.1	0.061	0.18	0.002
			NDVI Ratio		
H_m	0.08	0.23	0.001	0.29	0.03
Number of Nodes	0.11	0.03	0.07	0.19	0.003
HNR	0.0002	0.04	0.08	0.22	0.01
			WA		
H_m	0.12	0.62	0.004	0.12	0.01
Number of Nodes	0.25	0.01	0.01	0.02	0.04
HNR	0.01	0.22	0.04	0.15	0.007

At the same time the value of R^2 between number of nodes and $NDVI_{OR}$ decreased from July 10 (0.28) to July 18 (0.001), Table 7. This can be attributed to inconsiderable increase in the number of nodes (13.3 %) as compared to the increase in height (32.4 %) with increase in $NDVI_{OR}$ during that period. This result is in coherence with the fact that in cotton, the vegetative growth means relatively greater increase in plant height as compared to number of nodes. It means increase in average height per node distance, which is also known as HNR. The results observed for HNR, also support this implication as HNR showed a better relation with $NDVI_{OR}$ on July 18 (R^2 = 0.22) in comparison to July 10 (R^2 = 0.01). This is shown in Table 7. Also during the same period, percentage increase in HNR (17.2 %) was greater than percentage increase in number of nodes.

Table 8. R^2 values between parameters measured manually and measured using on-the-go sensor system for individual sampling dates for the long term fertility study

	Long term fertility study	
	July 12	August 9
	$NDVI_{OR}$	
H_m	0.39	0.36
Number of Nodes	0.14	0.47
HNR	0.1	0.0039
	$NDVI_{BR}$	
H_m	0.04	0.53
Number of Nodes	0.008	0.46
HNR	0.001	0.0082
	NDVI Ratio	
H_m	6.00E-06	0.52
Number of Nodes	0.0005	0.4
HNR	0.0016	0.017
	WA	
H_m	0.35	0.51
Number of Nodes	0.1	0.5
HNR	0.11	0.0017

From the results obtained, it can be said that during the period between July 10 and July 18 , unwanted vegetative growth took place. This emphasizes the importance for application of PGRs around this time in the season to limit vegetative growth and to increase the reproductive growth in cotton. Similar pattern in the results were also observed when $NDVI_{BR}$, NDVI Ratio and WA were compared with all three growth parameters (H_m, number of nodes and HNR) for July 10 and July 18 data (Table 7).

Table 9. Mean, standard deviation, minimum and maximum values of different parameters measured by sensors for different dates for the nitrogen rate study

DATE		$NDVI_{OR}$	$NDVI_{BR}$	NDVI Ratio	WA	H_s	H_m	Nodes	HNR
July 10	Mean	0.67	0.11	0.16	0.43	18.65	13.93	10.38	1.34
	Standard Deviation	0.04	0.01	0.02	0.02	1.28	0.89	0.57	0.06
	Minimum	0.59	0.09	0.14	0.38	16.28	12.40	9.40	1.20
	Maximum	0.73	0.13	0.21	0.47	21.00	15.60	11.20	1.42
July 18	Mean	0.76	0.22	0.29	0.53	25.72	18.45	11.76	1.57
	Standard Deviation	0.03	0.04	0.05	0.03	0.97	0.69	0.57	0.08
	Minimum	0.71	0.16	0.22	0.48	23.80	17.20	10.80	1.45
	Maximum	0.82	0.30	0.40	0.59	27.44	19.60	12.80	1.76
August 9	Mean	0.73	0.45	0.62	0.61	31.16	26.53	13.95	1.91
	Standard Deviation	0.03	0.04	0.04	0.03	1.49	1.43	1.08	0.14
	Minimum	0.66	0.36	0.55	0.53	28.25	24.00	12.20	1.64
	Maximum	0.76	0.52	0.69	0.65	33.50	29.60	16.40	2.14
August 13	Mean	0.73	0.45	0.61	0.61	31.11	26.14	12.68	2.06
	Standard Deviation	0.02	0.04	0.04	0.03	1.62	2.48	0.55	0.14
	Minimum	0.69	0.38	0.55	0.56	27.84	22.60	11.40	1.83
	Maximum	0.76	0.52	0.69	0.65	33.71	32.00	13.60	2.35
August 22	Mean	0.54	0.40	0.74	0.48	28.02	26.33	16.18	1.63
	Standard Deviation	0.03	0.04	0.09	0.02	1.25	1.69	0.92	0.12
	Minimum	0.50	0.33	0.58	0.44	25.33	23.80	14.80	1.38
	Maximum	0.58	0.49	0.93	0.52	29.74	29.80	17.60	1.82

Better relationship was observed between WA and H_m for July 18 data because WA is the weighted average of $NDVI_{OR}$ and $NDVI_{BR}$. Thus can be considered as a better indicator of vegetative growth. $NDVI_{BR}$ did not show any relation with the three growth parameters because at that time of the season there was no canopy closure, hence values of $NDVI_{BR}$ were very low. Similar results were observed for NDVI Ratio. In the test plots PGRs were applied after July 18. Therefore, once the natural growth behavior of crop was disturbed, relatively low correlations were expected between NDVI and cotton growth parameters related to the cotton height (Fig 8).

In the long term fertility study, the data for July 12 showed similar results as shown by July 10 data for the nitrogen study. This shows a common cotton growth behavior in both studies. On the other hand, in the long term fertility study, data for July 18 was not available. Therefore, it was difficult to draw any conclusions for change in behavior of cotton growth for the month of July (which was important for the application of PGR). In addition, better relationships were observed between manually measured cotton growth parameters and parameters measured by the sensors, for the long term fertility as compared to the nitrogen rate study for August 9 data. The reason for these results could be the fact that PGRs were not applied in the long term fertility study. Thus, the natural growth pattern of cotton was not disturbed as a result better R^2 values were observed between NDVI and cotton structural parameters for August 9 data. Table 10 shows the summarized data for different parameters measured by sensors for different dates for the long term fertility study. Another to be was relatively small values of NDVI for August 22 data (Table 9). The reason for this drop in NDVI could be the water stress in cotton,because it was observed that average NDVI values recorded after August 22 were greater than the average NDVI values recorded on August 22 (appendix B).

Table 10. Mean, standard deviation, minimum and maximum values of different parameters measured by sensors for different dates for the long term fertility study.

DATE		$NDVI_{OR}$	$NDVI_{BR}$	NDVI Ratio	WA	H_s	H_m	Nodes	HNR
July 12	Mean	0.76	0.15	0.19	0.50	24.47	18.16	11.26	1.62
	Standard Deviation	0.05	0.03	0.03	0.03	2.04	1.67	0.93	0.14
	Minimum	0.65	0.11	0.15	0.43	20.00	11.80	8.80	1.28
	Maximum	0.82	0.22	0.29	0.55	27.88	21.90	14.00	1.91
July 18	Mean	0.70	0.47	0.67	0.60	30.53	26.78	13.68	1.97
	Standard Deviation	0.04	0.10	0.12	0.06	3.01	3.26	1.60	0.21
	Minimum	0.61	0.21	0.34	0.45	24.36	19.00	8.60	1.66
	Maximum	0.76	0.60	0.83	0.69	35.05	32.20	17.40	2.50

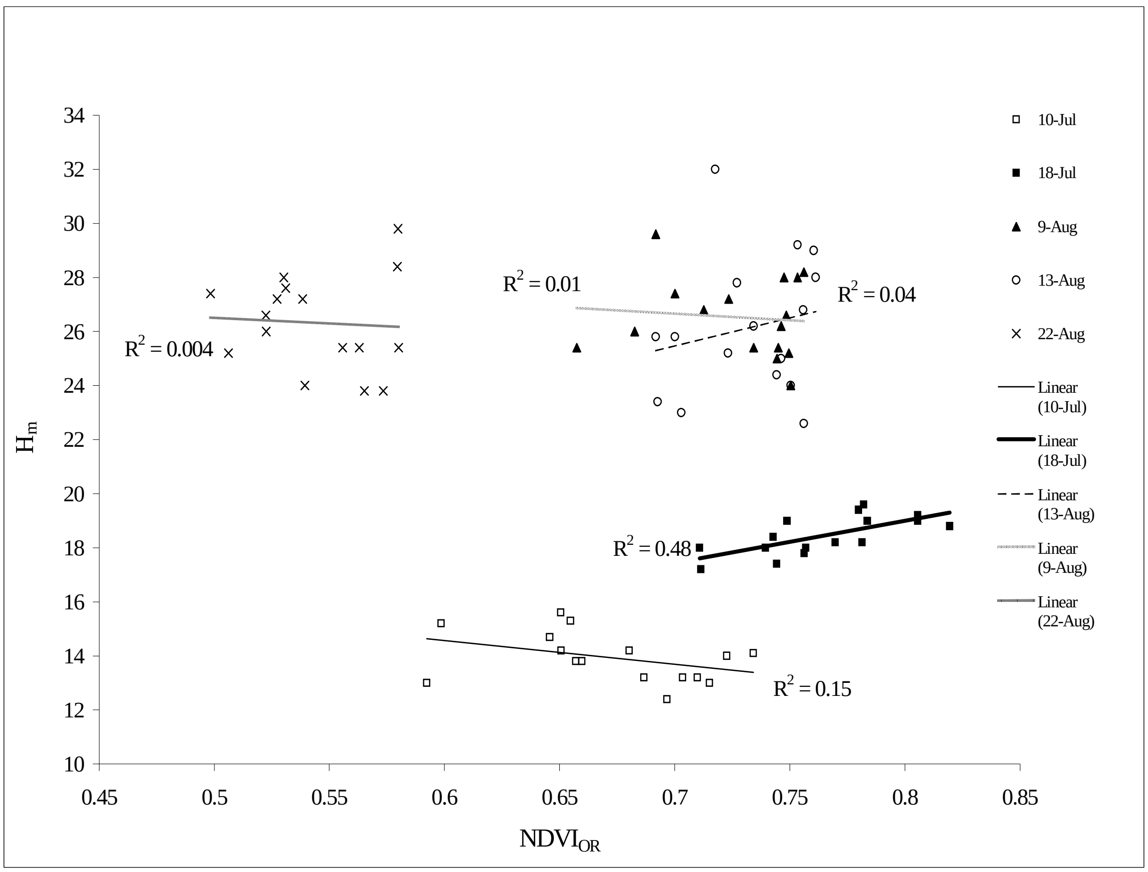

Figure 8. R^2 values for individual sampling dates between $NDVI_{OR}$ and Manual Height (H_m) for the nitrogen rate study

In addition, regression analysis was carried out on the cumulative data for the nitrogen rate study. Data for August 22 was not considered for this analysis because the NDVI values were unexpectedly small for that day. The results obtained from this analysis are shown in Appendix B. Regression analysis of cumulative data for two dates, July 10 and July 18 was also performed. This was done by assuming that the natural growth behavior of cotton was disturbed after the application of PGRs on nitrogen rate study (applied after July 18). Hence, data after application of PGRs could not be used for prediction of cotton growth parameters.

From the analysis it was observed that the value of R^2 for the cumulative data (four dates) was higher than the R^2 value obtained from data that was analyzed for individual sampling dates (Table 7). The reason for the higher values of R^2 could be the increase in the value of NDVI and values of different growth parameters with increase in number of days in the season, which gave a better slope to the regression line.

4.2.1 Height measured by the sensor (H_s) vs Height to Node Ratio (HNR)

The relation between H_s and HNR was also analyzed. The average cotton height was found to be 18.7 inches on July 10 (Table 9) for the the nitrogen rate study. Variation in HNR was 0.25 inches/node. Also no relation (R^2=0.001) between H_s and HNR was observed. With the increase in age of plant, the plant height increased to 25.7 inches on July 18. Better relation between HNR and H_s (R^2=0.46, Figure 9) was observed. At this time, variation in HNR was found to be 0.4 inches/node. This variation in HNR on July 18 was more than the variation observed in HNR on July 10 and could be a possible reason for the improvement in the value of R^2. For the long term fertility study, average crop height of 24.5 inches was observed on July 12 (Table 10) with a variation of 0.5 inches/node in HNR and value of R^2 as 0.07. The results for the nitrogen rate study and the long term fertility study are shown in Appendix A.The faster growth rate and large variations of cotton in the long term fertility study could be because of more fertile soil conditions. No conclusions were made about the prediction of HNR using H_s since data for July 18 for the long term fertility was available.

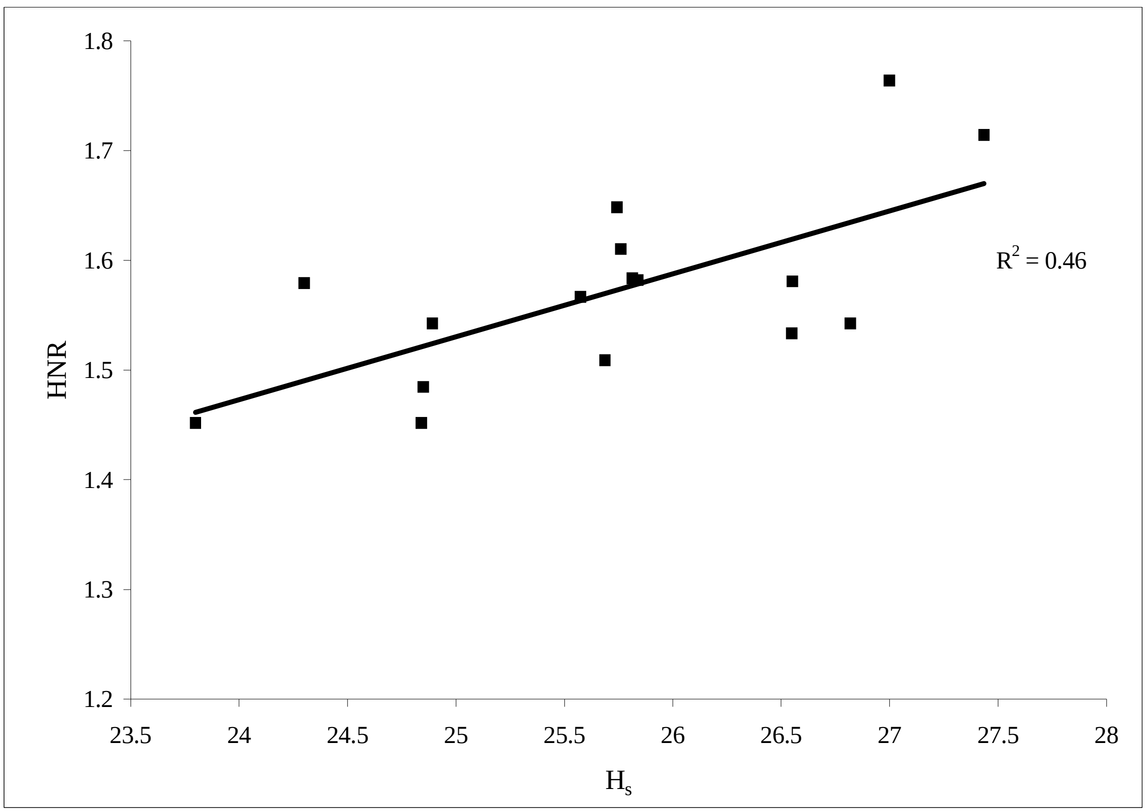

Figure 9. Regression analysis between Hs and HNR for July 18, 2007 for the nitrogen rate study

4.2.2 Multiple linear regression analysis

Multiple linear regression analysis was performed to find the best-fit model for H_m, using parameters measured by the sensors, for mid July data (July 18) for the nitrogen rate study. This corresponds to the time suitable for the application of growth regulators. Similar regression models were formed using both the standard least square method and stepwise linear regression analysis. The relationship was found to be highly significant ($p<0.01$, $R^2=0.62$) (eq. 4). H_m can also be written as a function of WA ($p < 0.01$, $R^2 = 0.62$, eq. 5, Fig 10). Either equation can be used to find cotton height.

$$H_m = 7.51 + (7.44 \times NDVI_{BR}) + (12.11 \times NDVI_{OR}) \quad (4)$$

$$H_m = 8.10 + (19.40 \times WA) \quad (5)$$

Where,

H_m = Manual Height in inches

$NDVI_{BR}$ = NDVI between the rows

$NDVI_{OR}$ = NDVI over the rows

WA = Weighted Average of $NDVI_{BR}$ and $NDVI_{OR}$

For the long term fertility study, the best-fit model for H_m was obtained using stepwise method for the July 12 data. It was seen that $NDVI_{OR}$ was significantly correlated with H_m ($p < 0.0001$, $R^2 = 0.47$). Hence, H_m can be written as a function of $NDVI_{OR}$ (eq. 6). In addition, it was observed that H_s was significantly correlated ($p < 0.0001$, $R^2 = 0.71$) with $NDVI_{OR}$ and $NDVI_{BR}$.

$$H_m = -1.14 + (25.54 \times NDVI_{OR}) \quad (6)$$

Both analysis techniques were also used to obtain the best-fit models for HNR in terms of sensed parameters. For the long term fertility study, the best-fit model was obtained with $NDVI_{OR}$ and $NDVI_{BR}$ for the July 12 data using the stepwise method. However, the model obtained was not statistically significant ($p = 0.0190$, $R^2 = 0.16$, eq. 7).

$$HNR = 0.84 + (1.43 \times NDVI_{BR}) + (0.77 \times NDVI_{OR}) \qquad (7)$$

Where,

HNR = Height to Node ratio

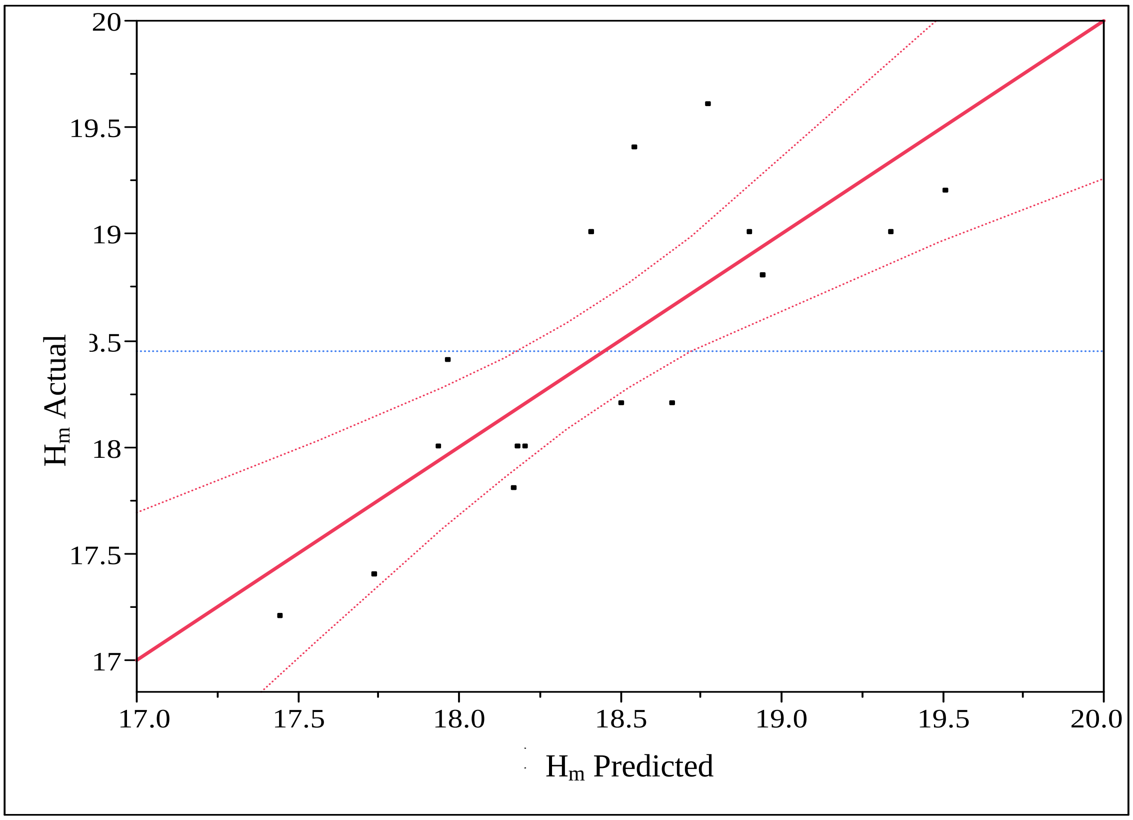

Figure 10. Regression model using least square method for height measured by the sensors and weighted average of NDVI for the nitrogen rate study for July 18, 2007

The best-fit model for the nitrogen rate study was obtained using stepwise method which composed of H_s only (Figure 11). The model was statistically significant (p = 0.0039, R^2 = 0.46). Hence, HNR can be represented as function of H_s (eq. 8). Quantity of PGR application is dependent upon HNR and H_s . The above results show that both of these parameters could be measured using ultrasonic sensors only. Therefore, it can be concluded that there is a possibility of using ultra sonic sensors for predicting PGR quatities for upland cotton. Since this implication is based on one data set only therefore it needs further study. It was found by step-wise analysis that HNR was also related ($p = 0.0679$, $R^2 = 0.22$) to $NDVI_{OR}$ (eq. 9).

$$HNR = 0.096 + (0.057 \times H_s) \quad (8)$$

$$HNR = 0.62 + (1.25 \times NDVI_{OR}) \quad (9)$$

Where,

H_s = Height measured by the ultrasonic sensor in inches.

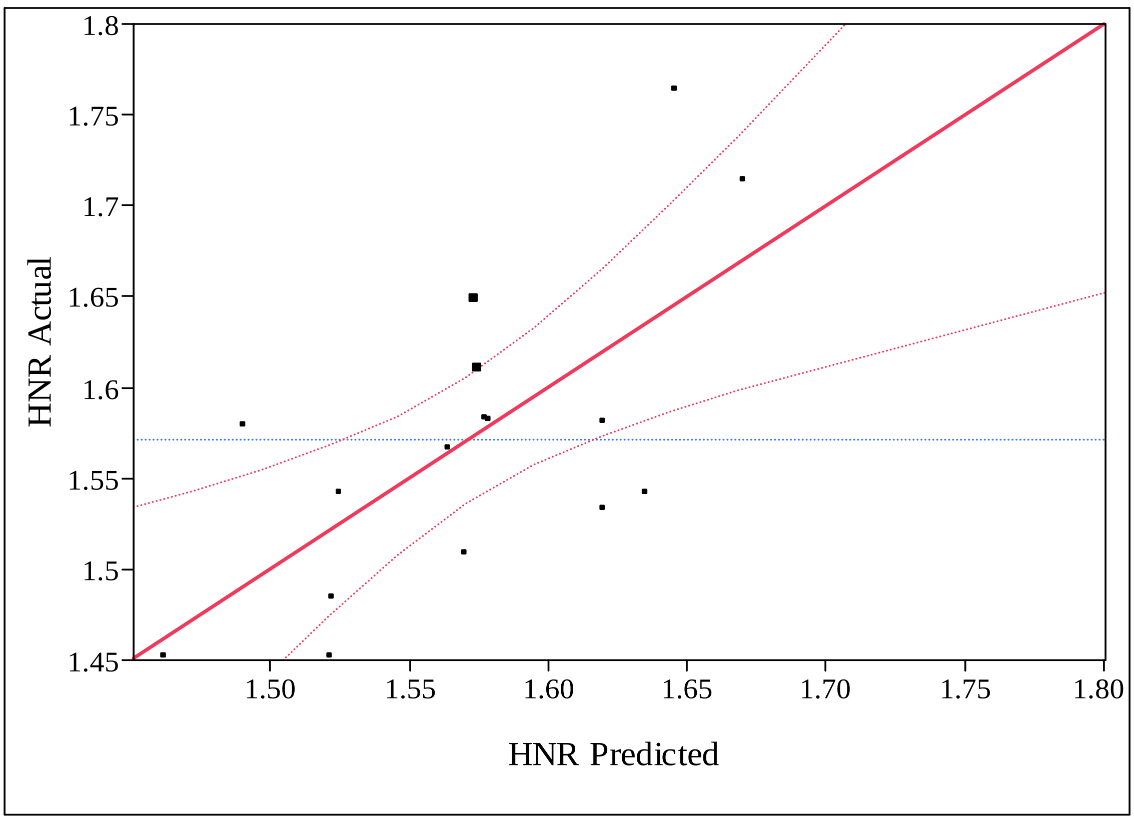

Figure 11. Regression model using stepwise method for HNR and H_s for July 18, 2007 for the nitrogen rate study

CHAPTER V

CONCLUSION

Plant height measured using on-the-go ultrasonic sensors was correlated with manually measured plant height (H_m from cotyledons to top of the plant). A linear relation was observed with $R^2 = 0.80$ between H_m and H_s when the data for all the dates was taken together. Hence, it can be concluded that ultrasonic sensors can be used to measure plant height. In addition, no correlation was observed between H_m and H_s when analyzed for individual sampling dates, for the nitrogen rate study except July 18 , where better relation was observed. Relatively higher R^2 values were observed for the long term fertility study. It was also observed that average height measured by the sensors (H_s) and average manual plant height (H_m) for each plot was significantly different and hence, are not comparable. However, when the height of cotyledons and the height of furrow were added to the manual height, total manual height and the height measured by the sensors were not found to be significantly different. Results obtained from cumulative data indicated that the height measured by sensors was comparable with the total height measured manually (height of cotyledons and height of furrow added to manual height).

$NDVI_{OR}$, $NDVI_{BR}$, NDVI Ratio and WA were compared with different cotton growth parameters such as HNR, number of nodes and H_m for both experimental studies, as shown in Tables 7 and 8. Some relation was obtained between parameter measured by the sensors and different structural parameters for July data for the nitrogen rate study. Greater increase in cotton height as compared to number of nodes from July 10 to July 18 indicated the presence of more vegetative growth. This was also shown in the data obtained from the nitrogen rate study. Relatively lower values of R^2 were obtained for mid-August sensor data with some structural parameters. For the long term fertility study, better relations were observed for August data between the parameters measured by the sensors and different structural parameters except HNR, which was not found to be related with NDVI. This was because, unlike the nitrogen rate study, the natural growth behavior of cotton was not disturbed for the long term fertility study by not applying the PGR.

Cotton structural parameters are used for the recommendations of plant growth regulators for cotton crop. In this study, cotton data for the month of July was used for PGR application when the extra vegetative growth is observed in cotton. Multiple linear regression analysis was performed to find the best-fit models to represent H_m and HNR for July data. It has been shown from the two experimental studies that manually measured plant height (H_m) can be represented as a function of NDVI. Therefore, in future experiments, plant height (H_m) can be measured using NDVI sensors. On the other hand, no significant model was observed for HNR as a function of NDVI. This proves that predictions for application of PGR cannot be made depending upon NDVI values. In addition, a relationship was observed between HNR and H_s for the long term fertility study, which opens a new possibility of using only ultrasonic sensors for prediction of PGR quantites. No conclusion can be made using only one set of data. Therefore, further study in this direction has been suggested. Also, no significant model was observed to represent number of nodes as a function of NDVI.

CHAPTER VI

FUTURE RECOMMENDATIONS

Though encouraging results were obtained indicating that the on-the-go sensor systems can be used for estimation of cotton growth parameters, there is a need to collect more data in order to validate the results obtained from this study for development of a real time PGR applicator. To validate the results of the on-the-go ultrasonic sensors for measuring cotton height, more height data should be recorded by the sensors and should be compared with the total manual height of cotton crop measured from the ground. Alternatively, a new method of measuring cotton height from the seed bed could be developed to evaluate the on-the-go sensor technology for measuring cotton crop height. Better linear regression model was observed to represent height to node ratio (HNR) by using only $H_{s.}$ Therefore, more studies should be conducted to verify the result, that only ultrasonic sensors can be used for the recommendations of PGR.

In addition, a study should be conducted using the same sensor system but on different variety of cotton to evaluate the use of sensor system in measuring the cotton structural parameters. Cotton structural parameters and parameters measured by sensors were found to be highly correlated in the different studies using remote sensing. For example $R^2 =$ 0.91 was observed between NACB and NDVI by Plant et. al. 2000. Therefore, a comparative study can be conducted using both the method of on-the-go sensor technology and remote sensing for the same experimental studies to evaluate the effectiveness of the use of on-the-go sensor systems in measuring the cotton structural parameters. Random error analysis for the use of on-the-go sensors should also be undertaken by conducting experiments in which the data of the same fields should be taken multiple times to find the relative error in the readings by applying different statistical methods. More intelligent programs should be made in MATLAB to avoid the use of ArcView GIS software as it can save the time for data processing in the future studies. Similar studies should be conducted with a large number of data points to validate the results.

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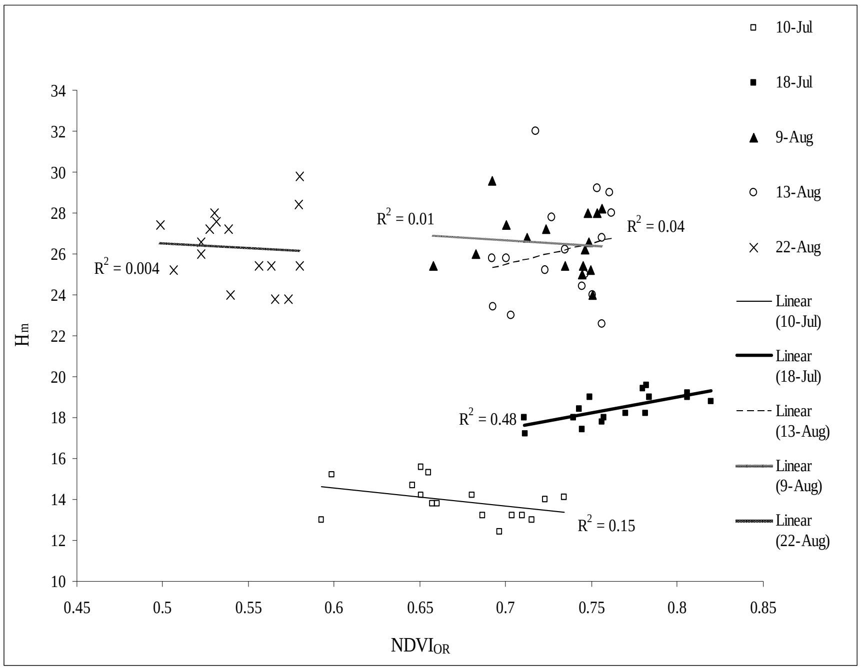
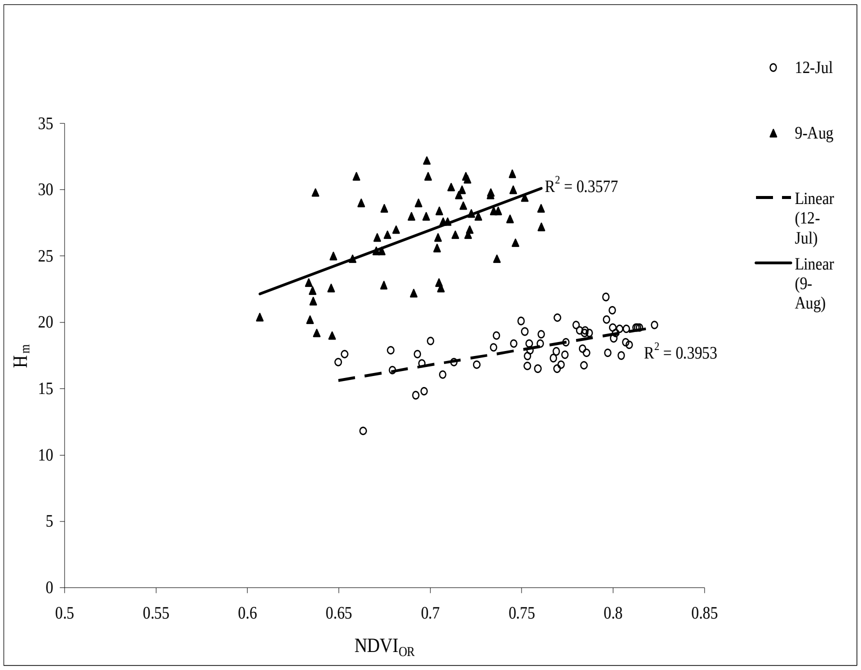
APPENDIX A

FIGURES



Date wise correlation between $NDVI_{OR}$ and Manual Height (H_m) for the nitrogen rate study



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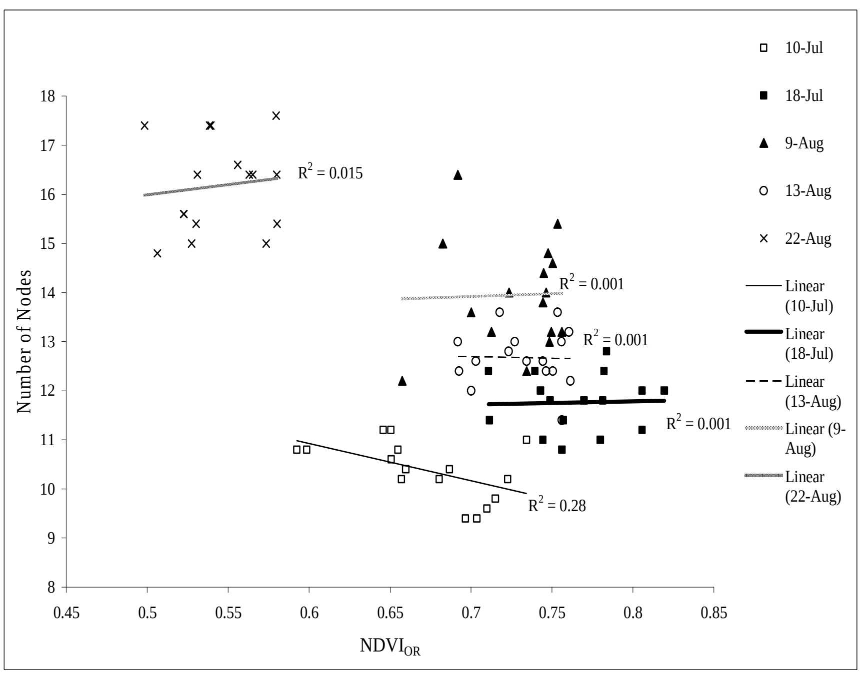

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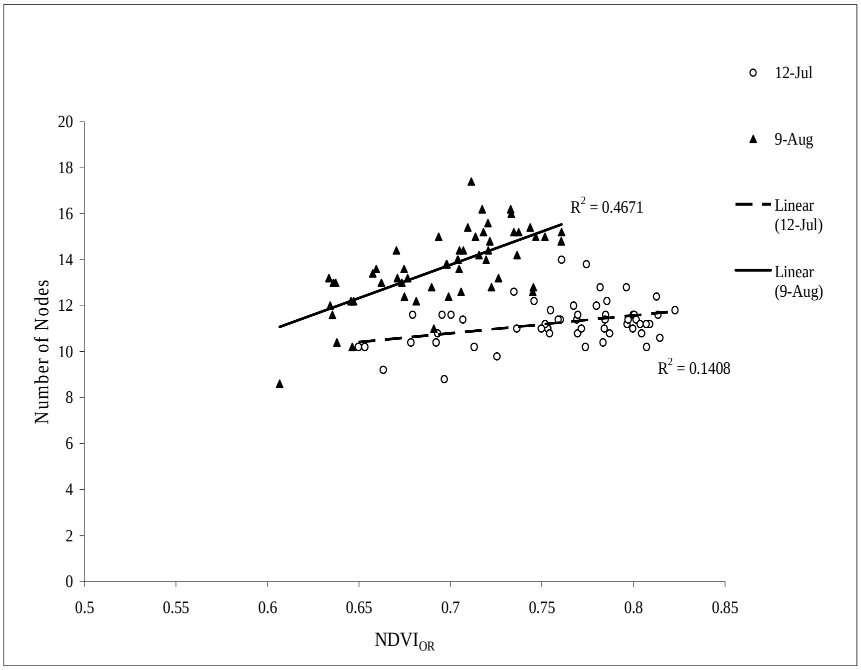

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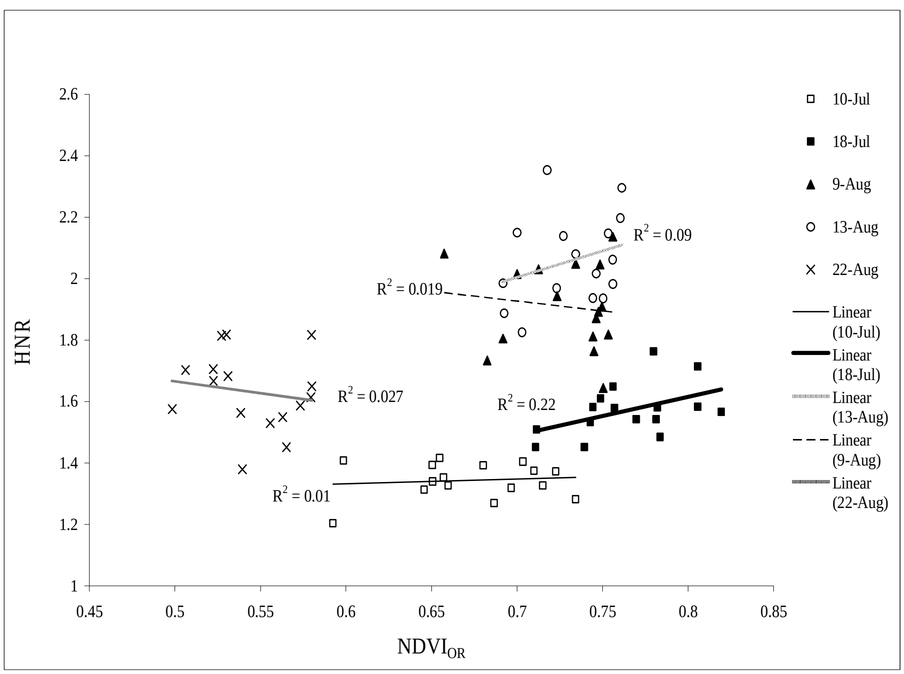
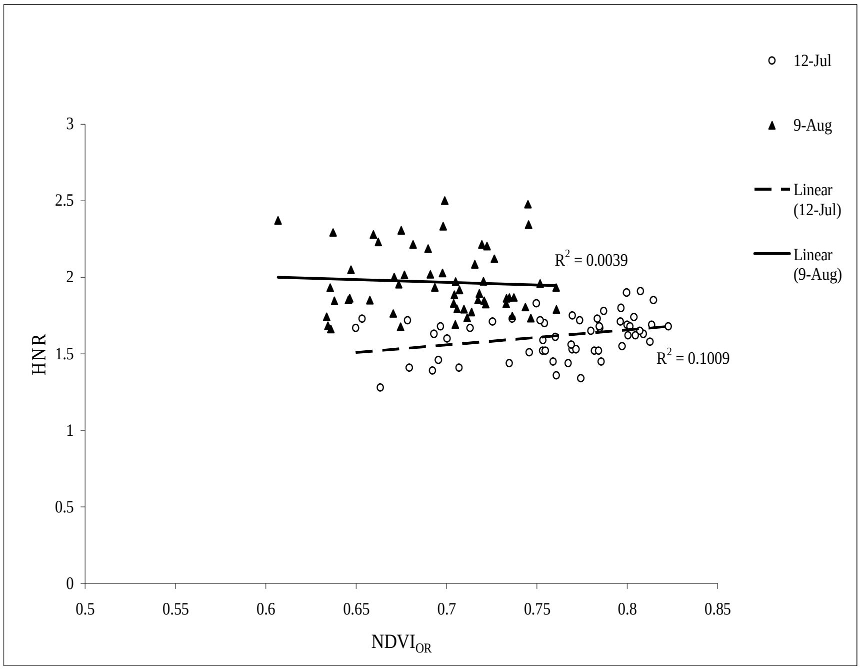


Date wise correlation between $NDVI_{OR}$ and height to node ratio (HNR) for the nitrogen rate study



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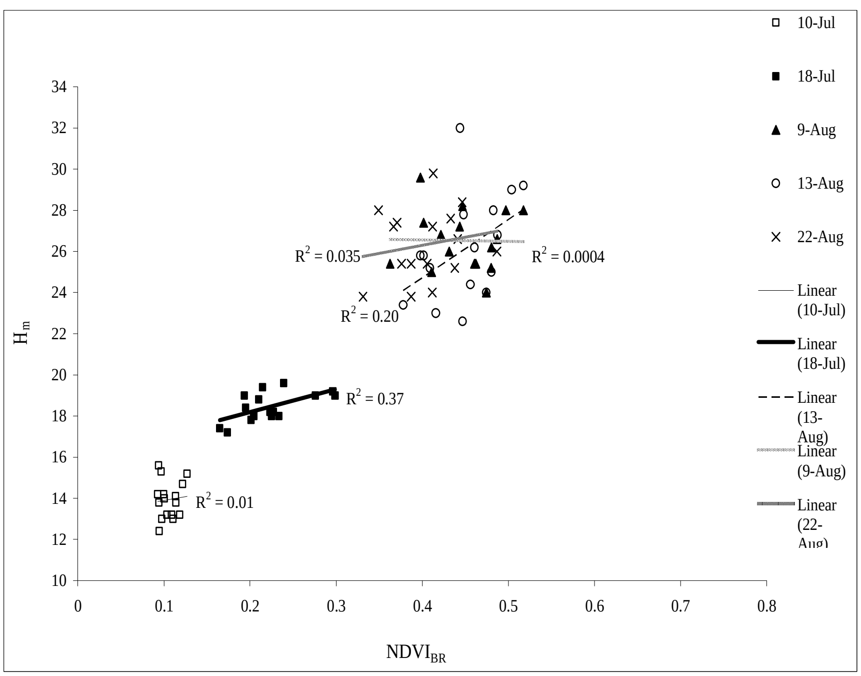

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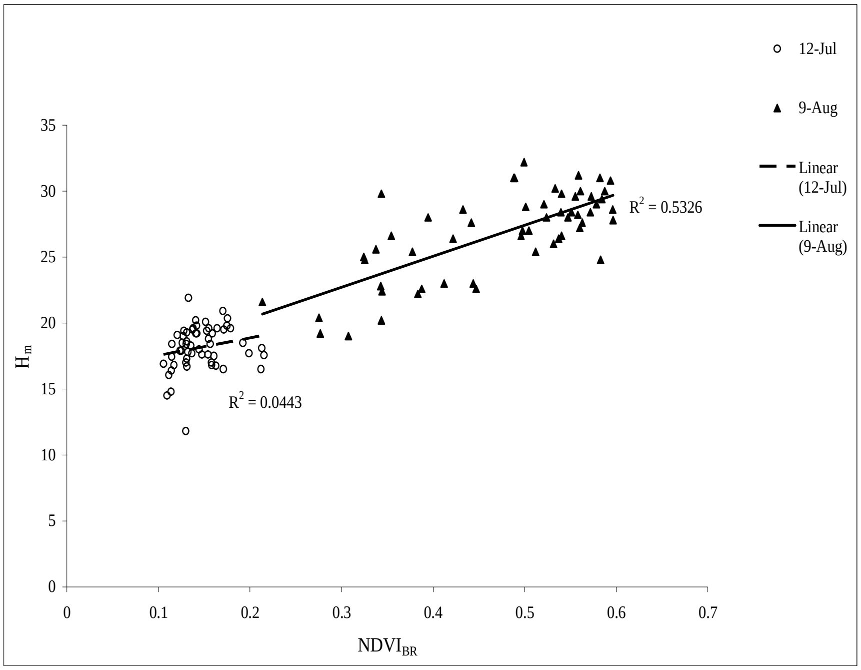

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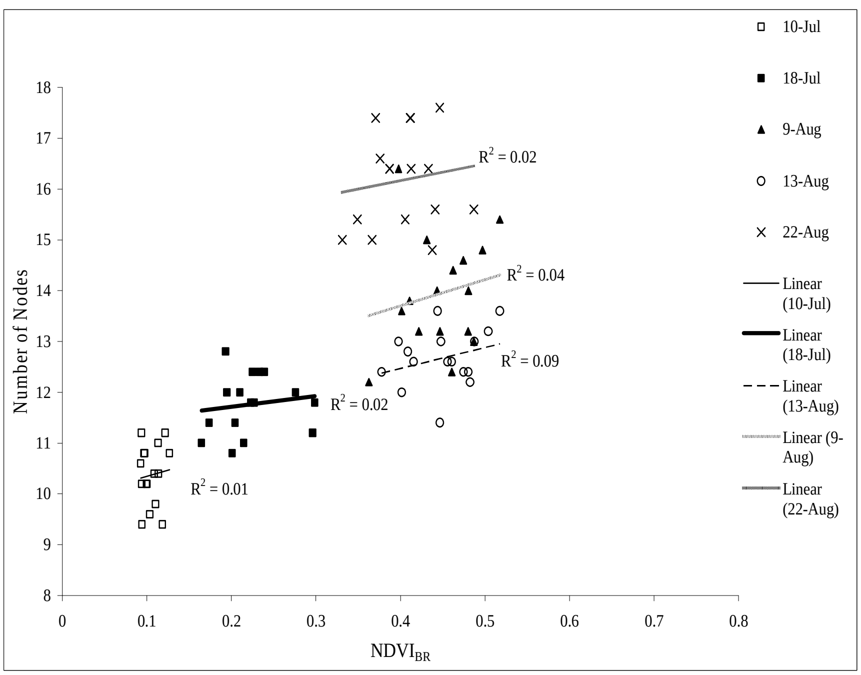
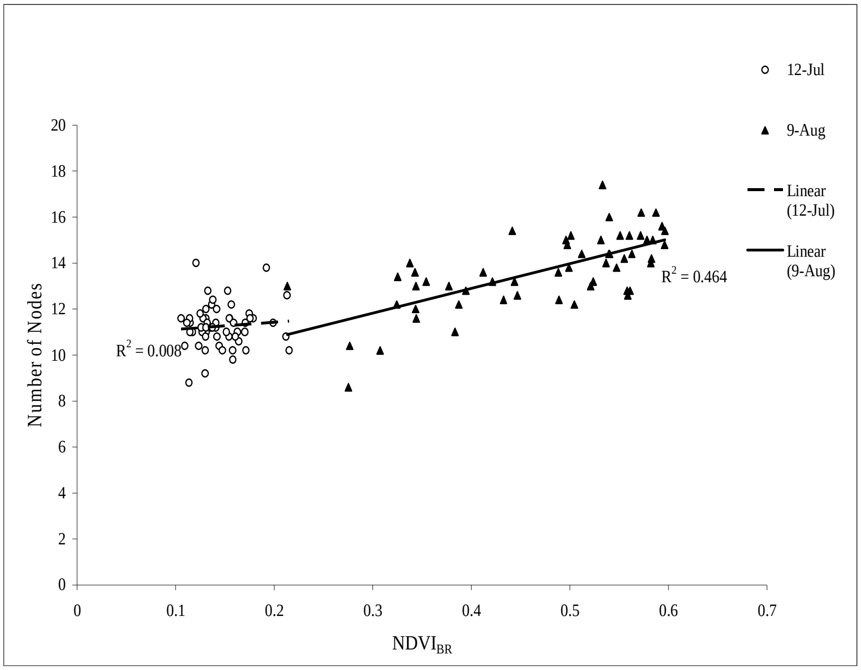


Date wise correlation between $NDVI_{BR}$ and number of nodes for the nitrogen rate study



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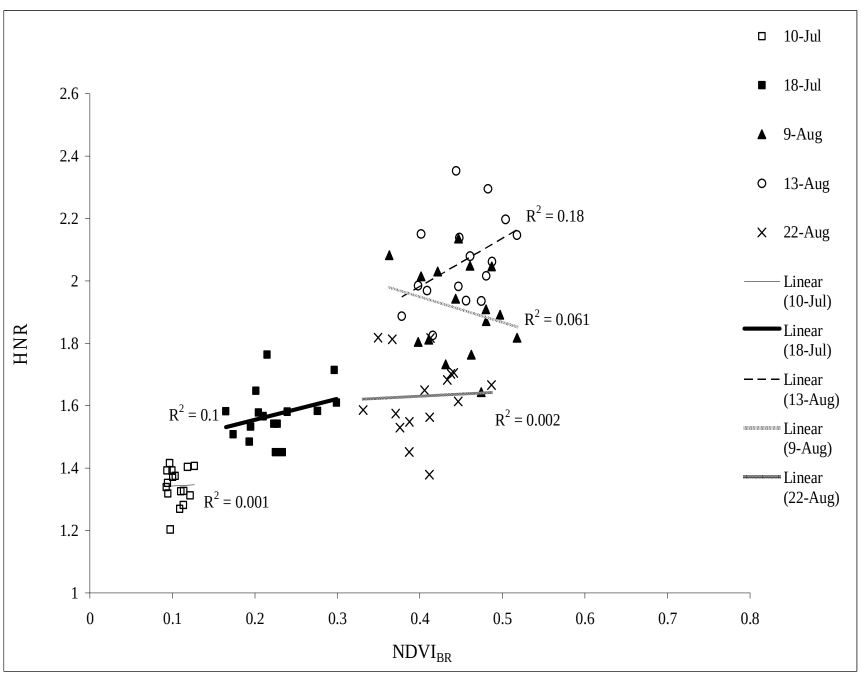

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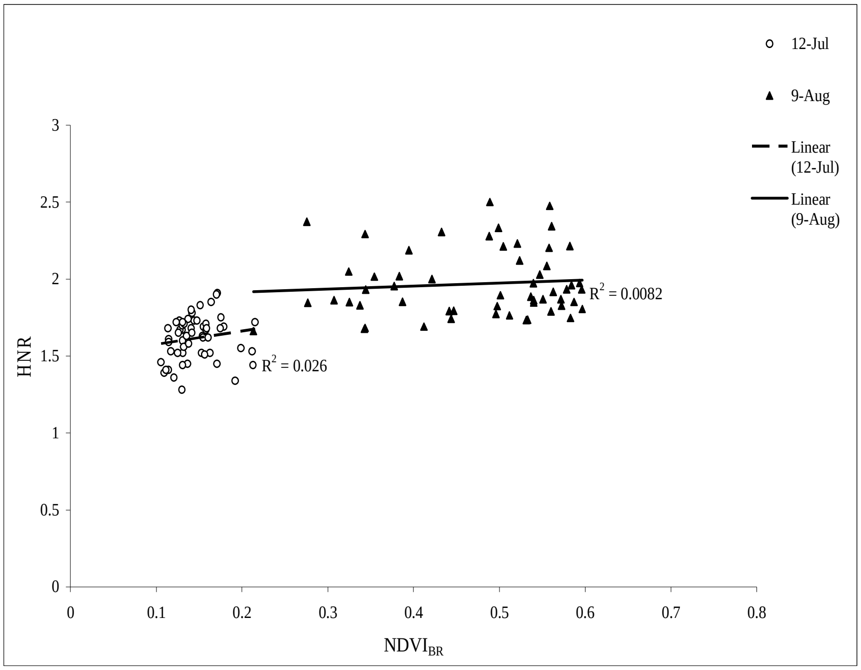

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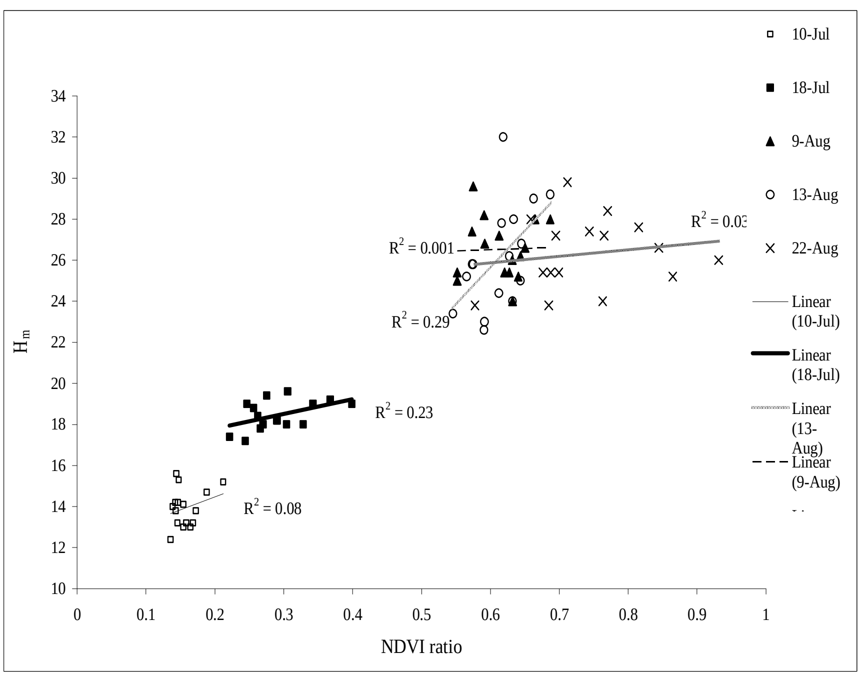
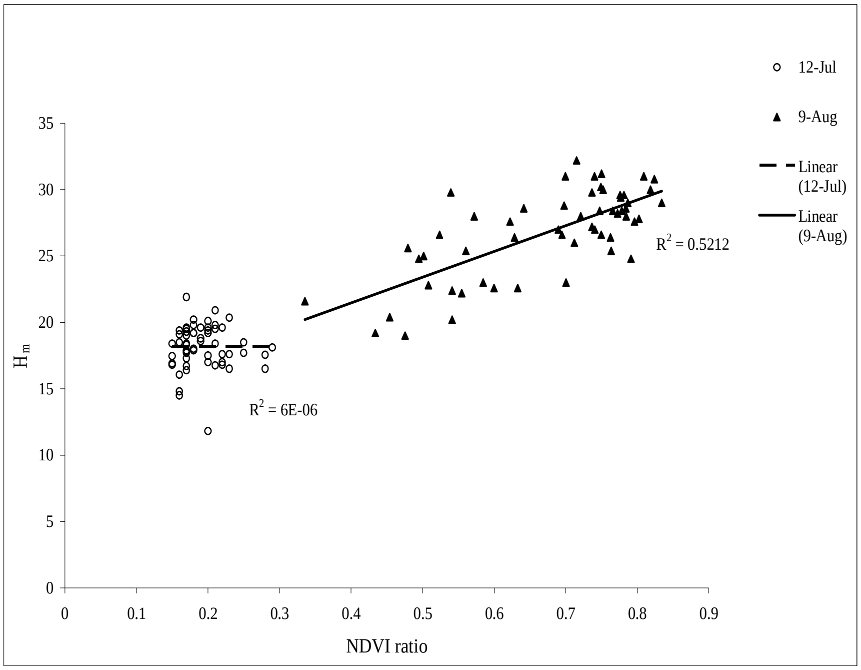


Date wise correlation between NDVI ratio and manual height (H_m) for the nitrogen rate study



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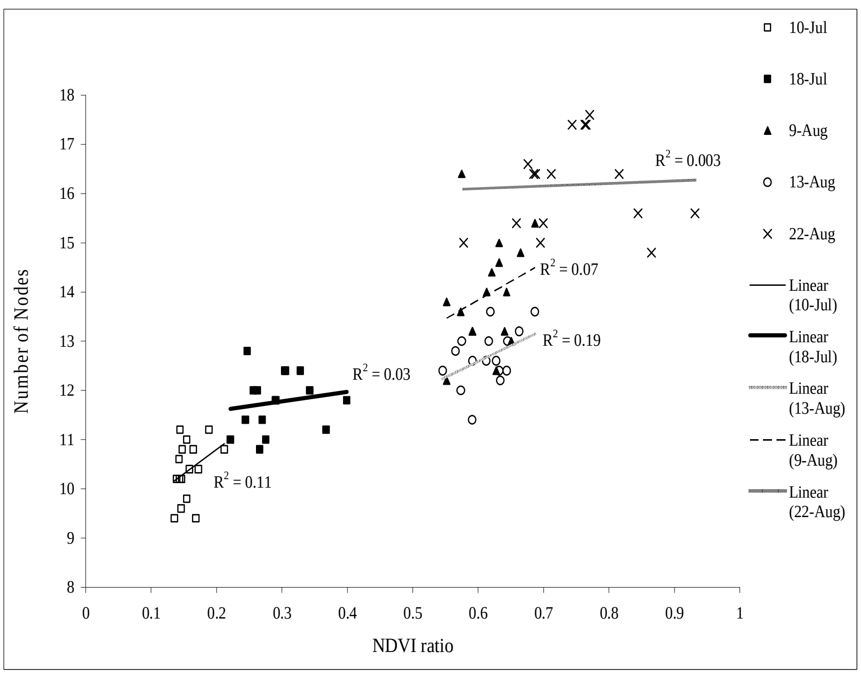

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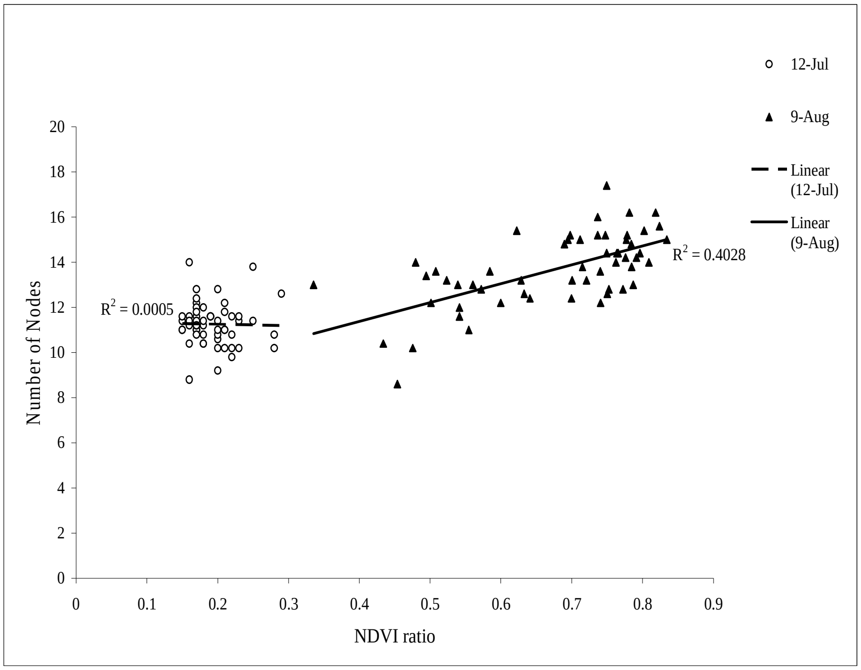

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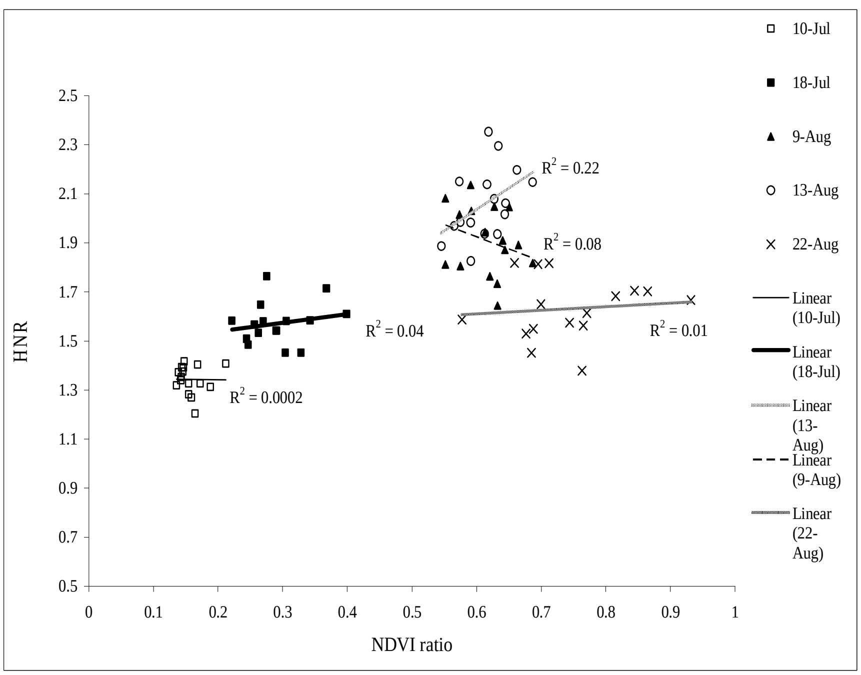

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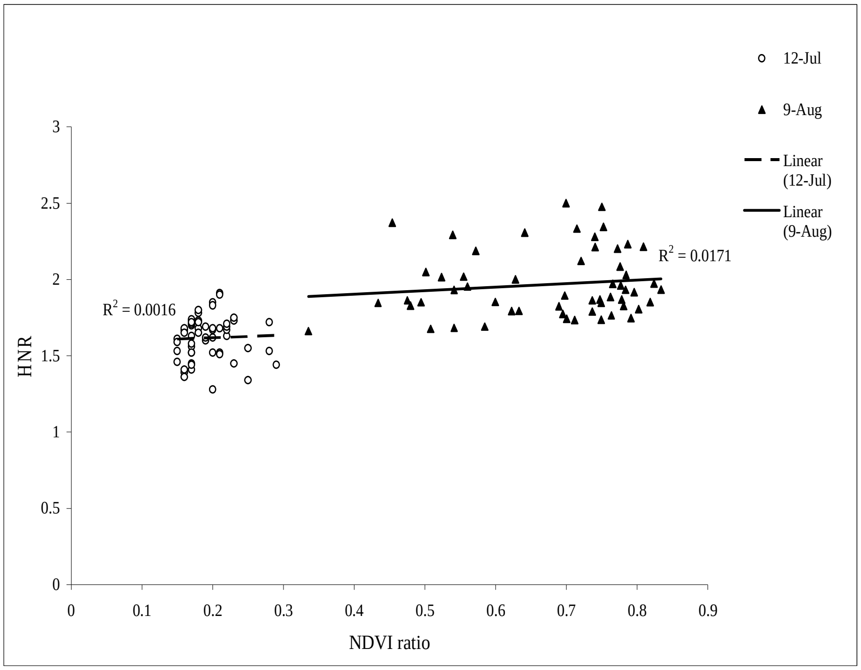

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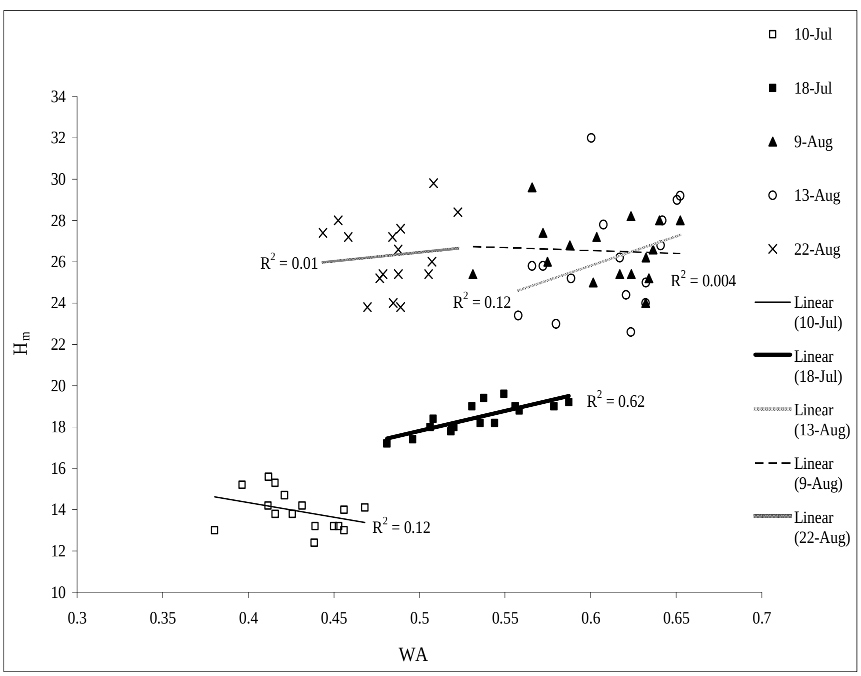
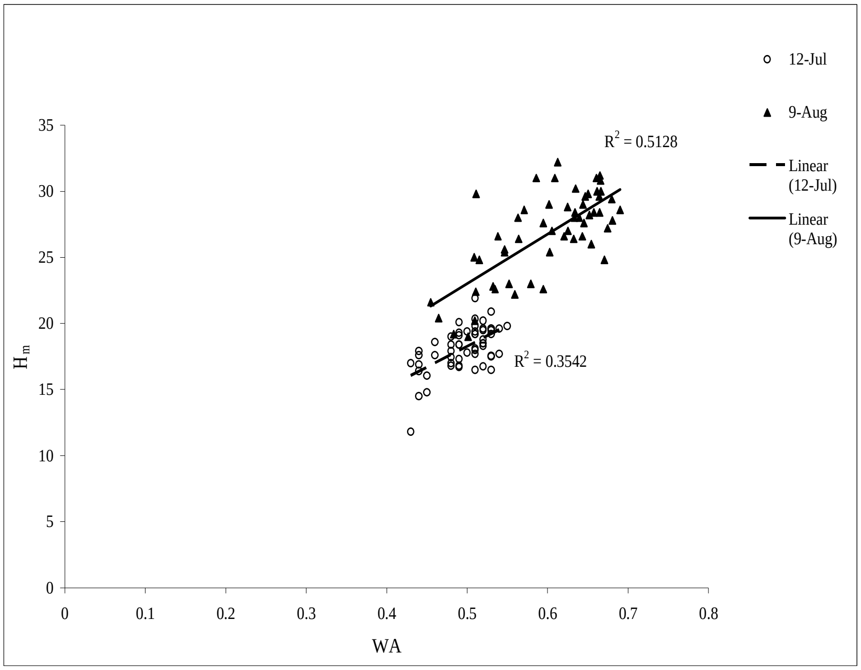


Date wise correlation between WA and manual height (H_m) for the nitrogen rate study



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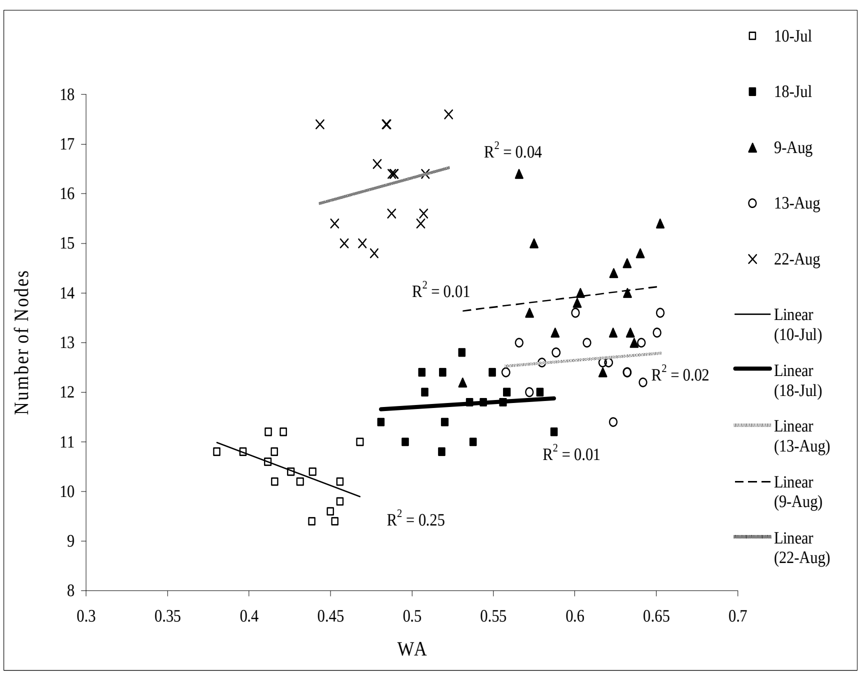

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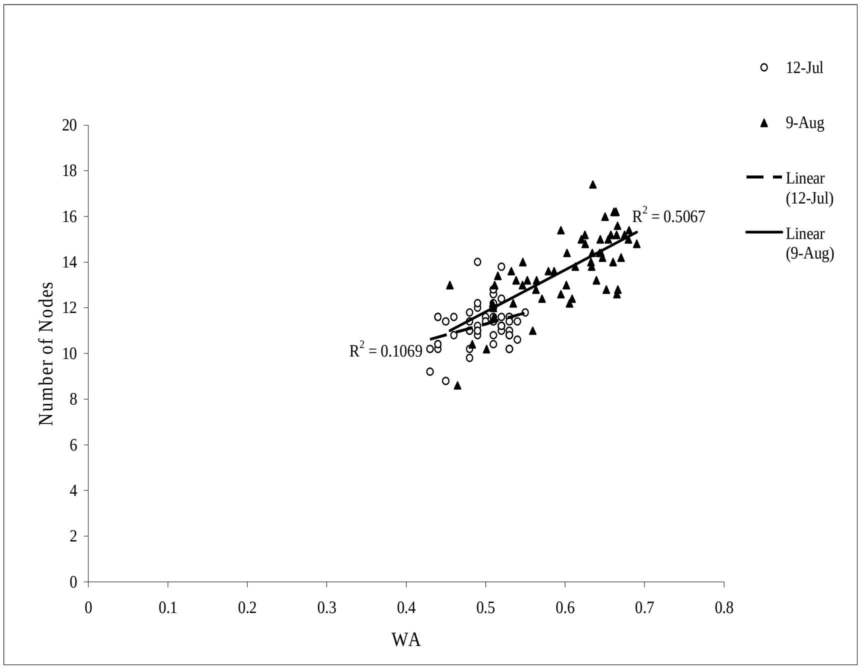

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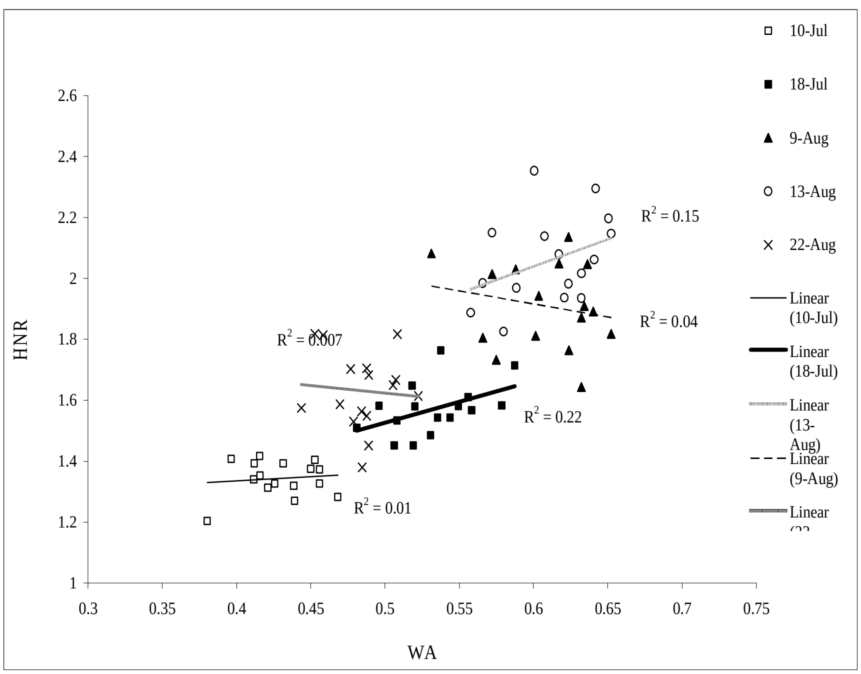
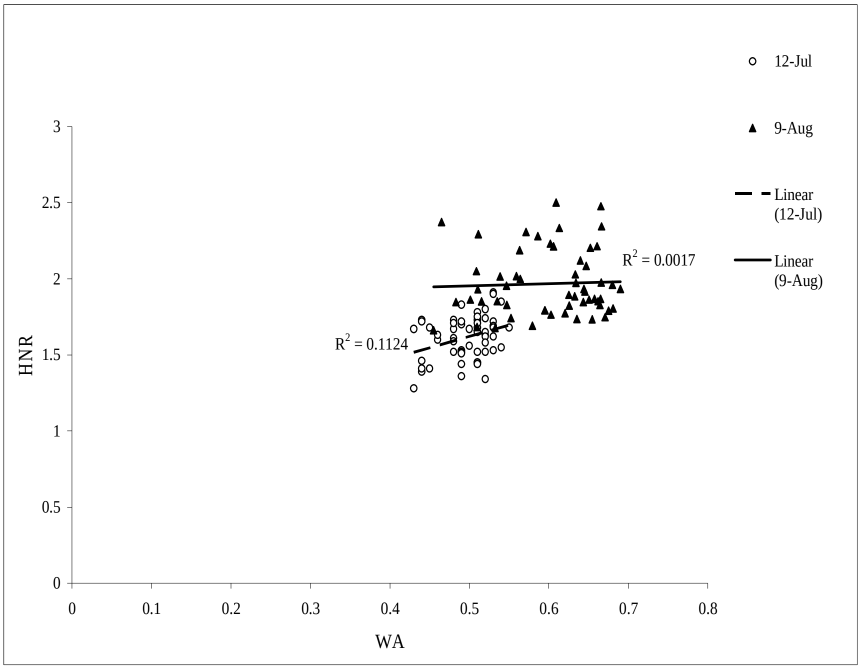


Date wise correlation between WA and height to node ratio (HNR) for the nitrogen rate study



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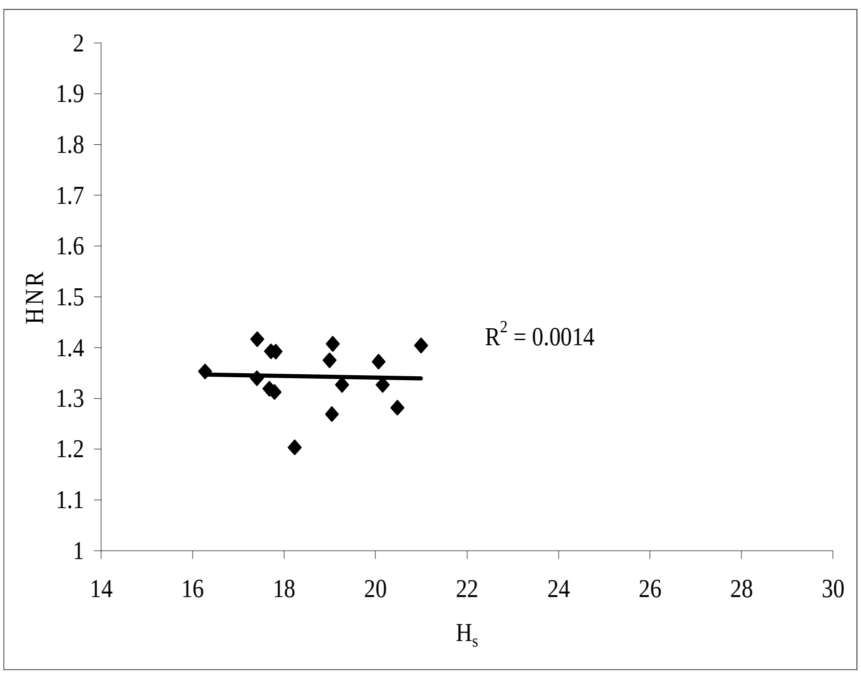
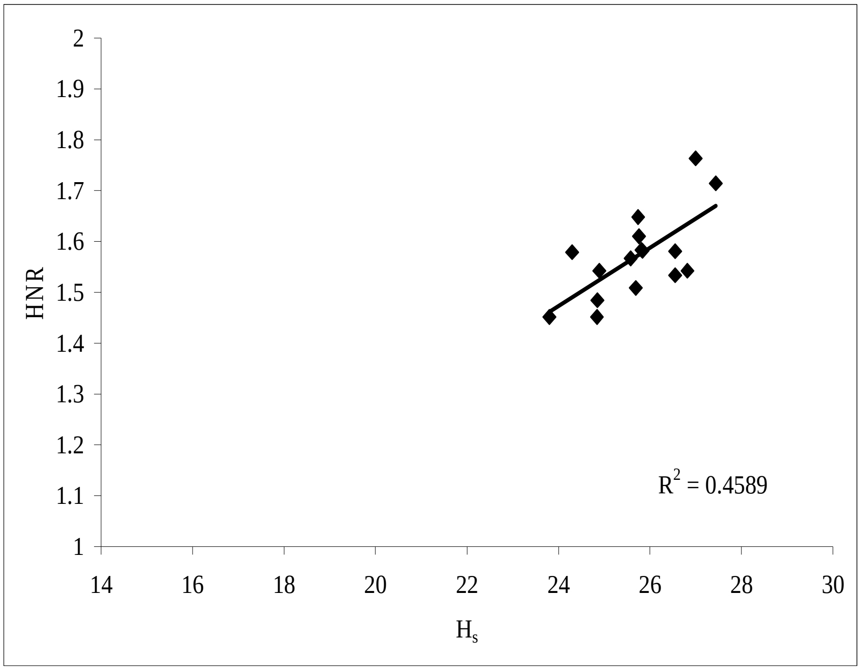
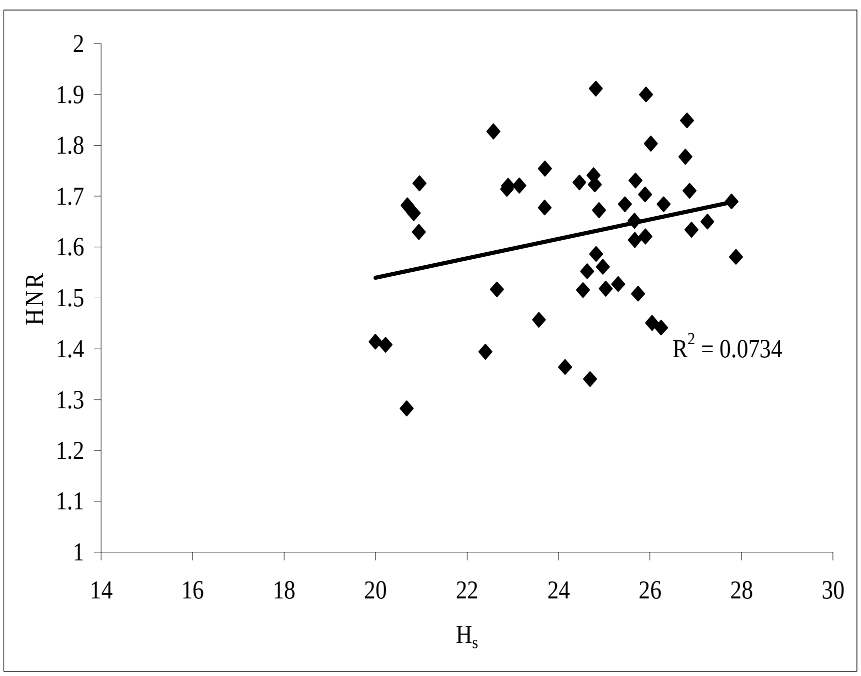


Regression analysis between Hs and HNR for July 10 ,2007 for the nitrogen rate study



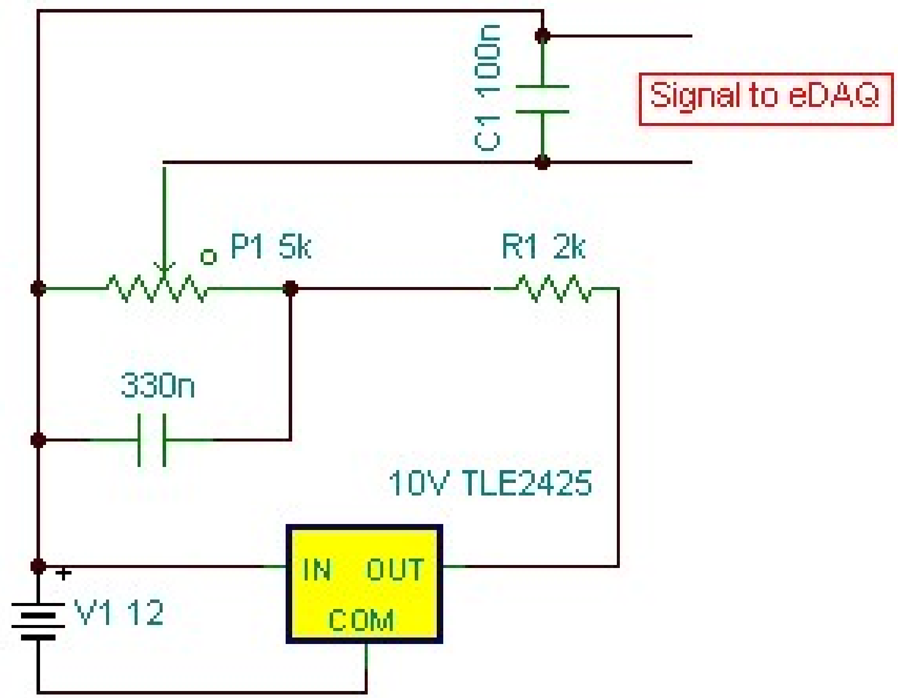
Regression analysis between Hs and HNR for July 18,2007 for the nitrogen rate study



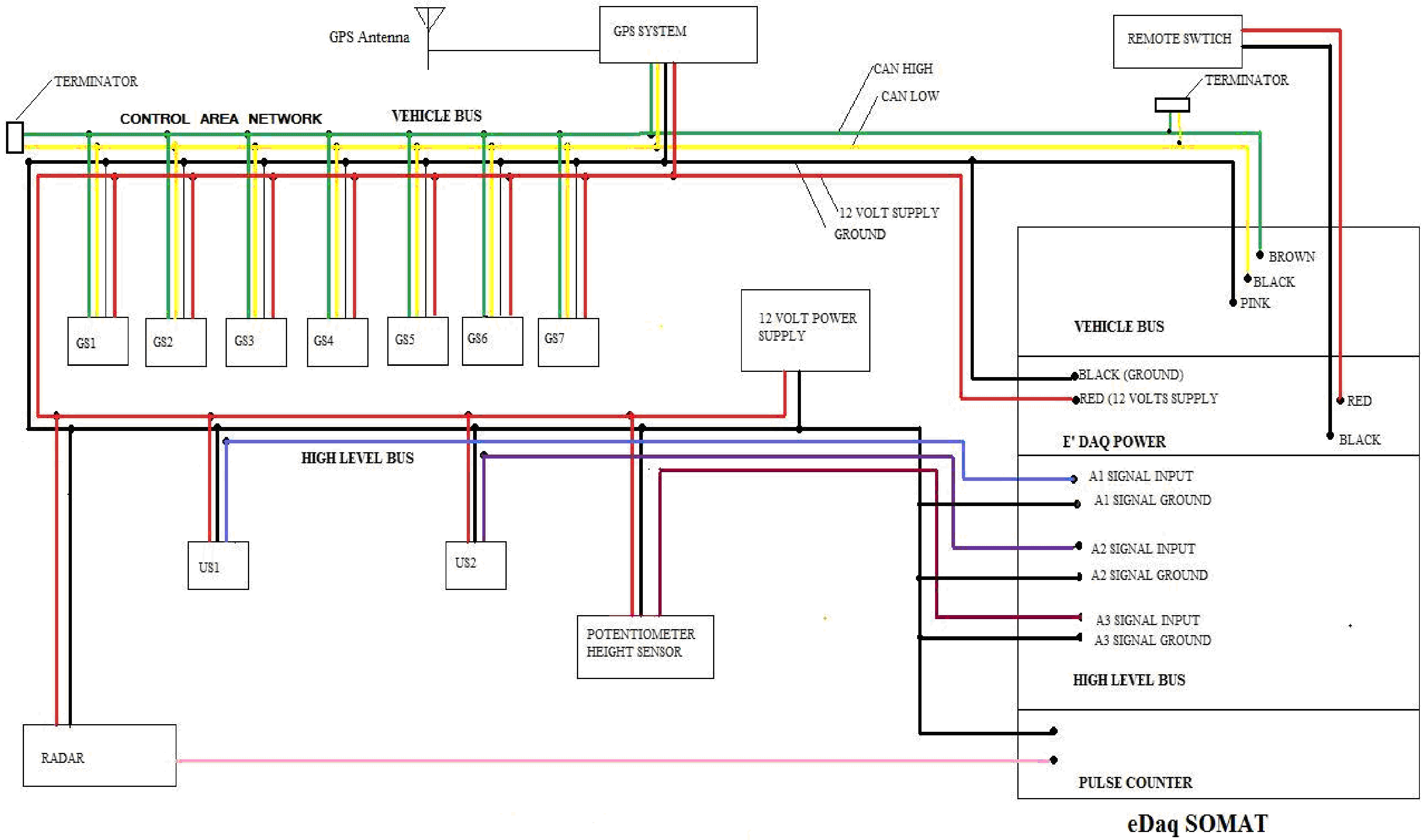
Regression analysis between Hs and HNR for July 12,2007 for the long term fertility study

CIRCUIT DIAGRAMS

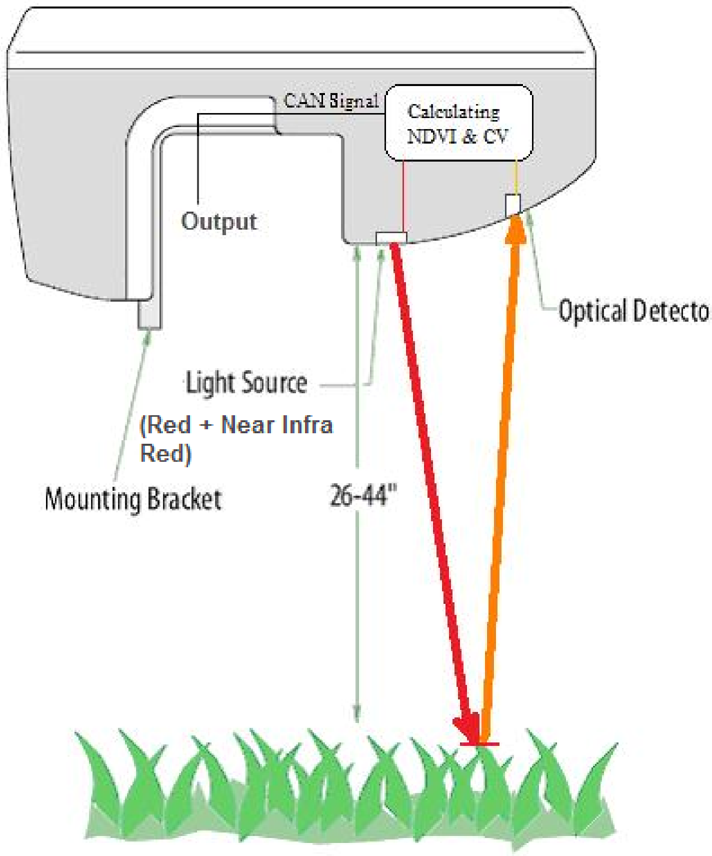
Circuit Diagram for Potentiometer Boom Height Sensor Signal Filter



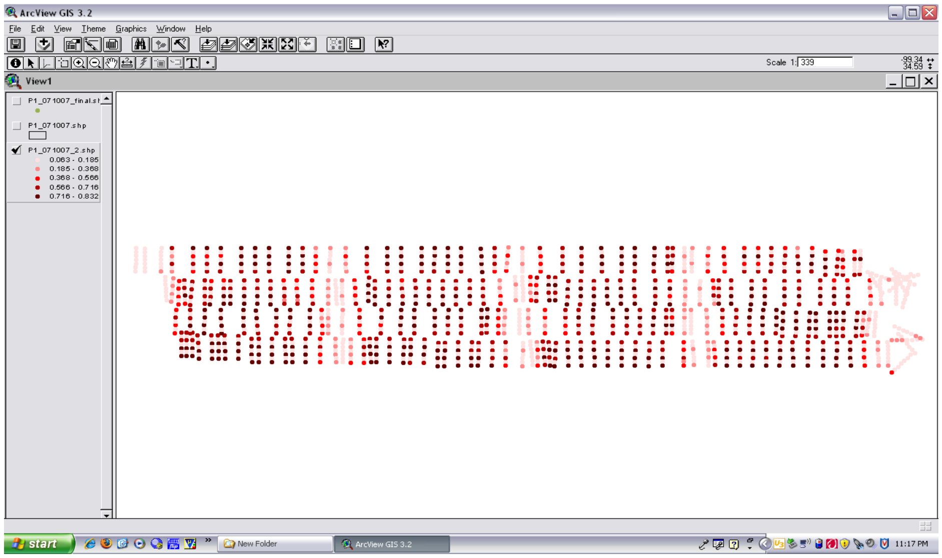
Wiring diagram of the sensor system

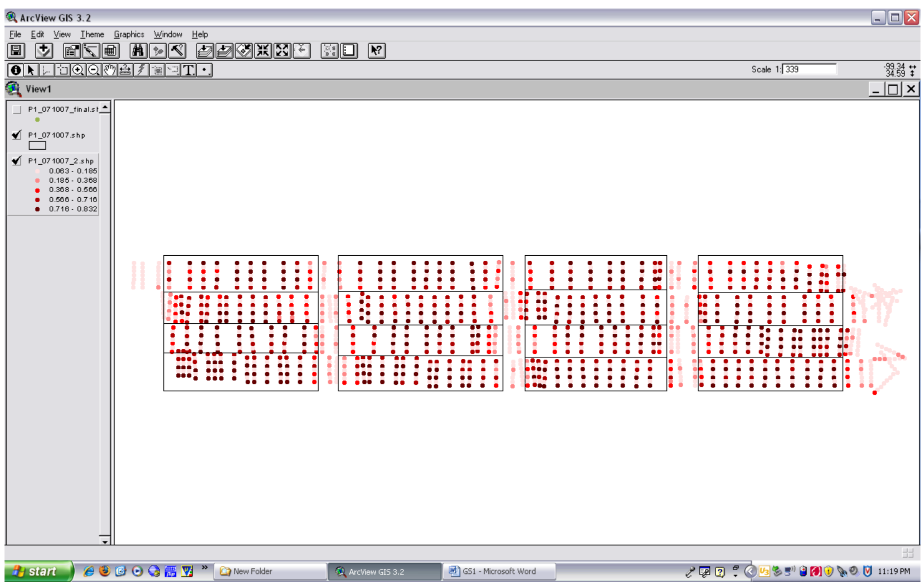


Working of the GreenSeeker® sensor



Pictures showing visual analysis using ArcView software





APPENDIX B

TABLES

Table1. Area in hectares under cotton for last five years in United States of America as obtained from USDA: Crop production Annual Summary

Year	Cotton All	Upland	American-Pima
2003	3974600	3880480	94120
2004	5008970	4848720	160250
2005	5585770	5477070	108700
2006	5152310	5021390	130920
2007	4246090	4129460	116630
Average	4793548	4671424	122124

Table2. Amount of cotton production in metric tones for last five years in United States of America as obtained from USDA: Crop production Annual Summary

Year	Cotton All	Upland	American-Pima
2003	3974600	3880480	71790
2004	5008970	4848720	100360
2005	5201480	5064200	137280
2006	4700190	4533540	166650
2007	4143950	3964330	179620
Average	4605838	4458254	131140

Table3. Values of R^2 for the combined data for the nitrogen rate study

	2 dates	4 dates
	$NDVI_{OR}$	
H_m	0.56	0.19
Nodes	0.25	0.08
HNR	0.58	0.01
	$NDVI_{BR}$	
H_m	0.82	0.91
Nodes	0.54	0.66
HNR	0.68	0.81
	NDVI Ratio	
H_m	0.65	0.92
Nodes	0.63	0.69
HNR	0.85	0.84
	WA	
H_m	0.76	0.83
Nodes	0.41	0.57
HNR	0.71	0.77

Table4. Mean, standard deviation, minimum and maximum values of different parameters measured by sensors for August 22 and September 26 for the nitrogen rate study

DATE		$NDVI_{OR}$	$NDVI_{BR}$	NDVI Ratio	WA
August 22	Mean	0.54	0.4	0.74	0.48
	Standard Deviation	0.03	0.04	0.09	0.02
	Minimum	0.5	0.33	0.58	0.44
	Maximum	0.58	0.49	0.93	0.52
September 26	Mean	0.66	0.47	0.72	0.58
	Standard Deviation	0.03	0.05	0.06	0.03
	Minimum	0.60	0.36	0.58	0.51
	Maximum	0.70	0.55	0.84	0.64

VITA

Amit Sharma

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Master of Science

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Professional Memberships:
American Society of Agricultural and Biological Engineers

Name: AMIT SHARMA Date of Degree: May, 2009

Institution: Oklahoma State University Location: Stillwater, Oklahoma

Title of Study: ON-THE-GO SENSOR TECHNOLOGY FOR COTTON MANAGEMENT

Pages in Study: 65 Candidate for the Degree of Master of Science

Major Field: Biosystems Engineering

Scope and Method of Study: This study was conducted on cotman cotton using on-the-go sensors. The aim of this study was to evaluate the use of on-the-go sensor technology to map cotton for the application of PGR. On-the-go sensor system can be used to make automatic real time PGR and defoliant sprayer in future and can limit the use of remote sensing and aerial imagery which is otherwise very expensive, needs lot of lab work and can not be used to make automatic real time sprayers.

In this study on-the-go NDVI sensors and ultrasonic height sensors were used to evaluate relationships between NDVI, plant height measured by the sensors and different cotton structural parameters. Also to define, cotton structural parameters as function of NDVI and plant height measured by the on-the-go sensors. For this, experiments were conducted near Altus, OK in 2007. Different nitrogen treatments were given to the different plots with in the field to creat spatial variability for height and NDVI. Data measured by sensors were compared with manually measured crop structural parameters recorded at different growth stages.

Findings and Conclusions: Manually measured plant height was observed as a function of NDVI, which infers that NDVI sensors can be used to measure cotton height. Height to node ratio was also found to be correlated with NDVI with low level of significance. On the other hand height to node ratio was found to be correlated with cotton height measured by the ultrasonic sensors with high level of significance. Also it was concluded that the plant height can be measured using on-the-go ultrasonic sensors, which brings the possibility that only ultrasonic sensors can be used to determine the rate of PGR application. Although, some satisfactory results were observed but still there is need to validate the results obtained in this study. In addition, some recommendations, related to testing of on-the-go sensor technology, have been suggested in the section on future recommendations. These recommendations can help in validating the results obtained in this study.

ADVISER'S APPROVAL: Dr. Paul Weckler