SITE-SPECIFIC MANAGEMENT OF COTTON PRODUCTION USING REMOTE SENSED THERMAL IMAGERY WITHIN A CONSERVATION TILLAGE SYSTEM

John Fulton, Dana Sullivan, Joey Shaw, Mark Dougherty, and Geoff Bland
Auburn University, 200 Corley Bldg, Auburn, AL 36849
fultojp@auburn.edu

Abstract

Thermal infrared (TIR) imagery has shown promise for early detection of crop stress while conservation tillage practices have provided benefits to cotton production. The objective of this investigation was to evaluate cotton production on rolling terrain irrigated with subsurface-drip irrigation (SDI) while using TIR for in-season detection of cotton response to irrigation and management in Northern Alabama. A 15-acre field located at the Tennessee Valley Research and Extension Center (TVREC) was used for this study and is managed as a no-tillage, continuous cotton system. Treatments consisted of irrigation (SDI vs. non-irrigated) and crop residue cover (cover vs. no-cover). TIR imagery was acquired in-season using an unmanned aerial system equipped with a TIR sensor. Results indicated that TIR emittance correlated well with canopy cover ($r = -0.44$, $alpha < 0.05$) and stomatal conductance ($r= -0.48$, $alpha < 0.05$). Differences between irrigated and non-irrigated plots existed with irrigated yields over 50% higher. Cover treatments yielded higher than no cover. Results from this investigation showed promise that TIR imagery could be used for site-specific management of cotton.

Introduction

The production of cotton plays an important role in the row crop agricultural economy in Alabama. Production systems using conservation tillage have been successfully adopted showing benefits for both soil and water conservation. However, drought continues to negatively affect yields while generating considerable yield variability within and between years depending on the timing and adequacy of rainfall. New technologies offer the opportunity to integrate precision agriculture techniques with precision irrigation technology to maximize yield each year while optimizing the use of production inputs such as fertilizer, agricultural chemicals, and seed. These technologies include pressure compensated subsurface drip irrigation (SDI) and the use of unmanned aerial vehicles (UAV's) to collect remote sensed imagery cost effectively.

Pressure compensated SDI offers a method to apply subsurface water uniformly on rolling terrain by maintaining uniform emitter flow over a range of operating pressure differences. Traditional or non-pressure compensating SDI is impacted when installed on rolling terrain because gravity causes more water to be distributed down slope. System design and management is a major factor in determining application uniformity. Due to the nature of the system, emitter clogs, crimped lines or other subsurface issues are not visible. Once crop stress is observed, oftentimes the effects are identified too late and result in yield loss. Better methods for determining issues is needed so they can be corrected in a timely fashion to minimize potential impacts on yield.

Past research has reported that reflectance and emittance spectra data can be used to evaluate in situ crop stress (Colwell, 1956; Jackson et al., 1983; Penuelas et al., 1993; Shanahan, 2001). Recent development of high spatial and spectral resolution sensors, collection of remote sensed data applications for site-specific and irrigation management, soil sampling and potential problem areas are being investigated. However, the expense and timeliness of obtaining high resolution remotely sensed imagery has limited the adoption of it by crop producers. The use of low-altitude UAVs for acquiring imagery on crop fields is a technique that has not been well-investigated. Simpson et al. (2003) acquired VIS and NIR imagery via a UAV to differentiate between variable nitrogen rates and water treatments in a corn canopy. Herwitz et al. (2002) used an UAV to assess field equipped with a multispectral camera and found reflectance patterns from the coffee tree canopy were positively related to yield.

The use of thermal infrared (TIR) sensors has been limited to date due to timeliness of data acquisition, data delivery and spatial resolution constraints. Barnes et al. (2000) found a linear relationship existed between the crop water stress index (CWSI) and soil water depletion when they evaluated a prototype sensor (VIS, NIR and TIR) mounted to an irrigation system to assess nitrogen and water stress within a cotton field. However, while TIR shows promise for use in in-season evaluation of crop stress, additional research is needed to fully establish its potential. Therefore, the objective of this investigation was to evaluate cotton production on rolling terrain irrigated with subsurface-drip irrigation (SDI) while using TIR for in-season detection of cotton response to irrigation and management in Northern Alabama.

Materials and Methods

A 15-acre field located at the Tennessee Valley Research and Extension Center (TVREC) in Belle Mina, Alabama was selected for this investigation. The field consists of Decatur silt loam and Decatur silt clay soils with slopes ranging from 1% up to 6%. The site is managed as a no-till, continuous cotton system with Soil fertility management was conducted according to Alabama Cooperative Extension System guidelines. The experimental design is a randomized block design with two irrigations treatments (Irr – irrigated; No Irr – non-irrigated) and two cover crop treatments (C – Cover; NC – No Cover) with four replications. Plot measure 27 ft by 1250 ft. The two cover crop treatments consist of a no cover and a winter wheat (*Triticum aestivum* L.) cover crop. Irrigation treatments include dryland versus pressure compensated sub-surface drip irrigation (SDI). SDI tape was installed on 80-in spacing between every other plant row at a nominal depth of 13 inches. In 2006, cotton was planted on April 18 using a 40-in. row spacing while irrigation was initiated on May 26. Irrigation was scheduled based on pan evaporation and adjusted for canopy closure, triggering an irrigation event at 60 % pan evaporation. This level was selected based on 6 years of prior SDI research on cotton at the same research facility (Fulton et al., 2005). Figure 1 presents the accumulated precipitation, pan evaporation, and irrigation on a monthly basis for the 2006 growing season at TVREC.

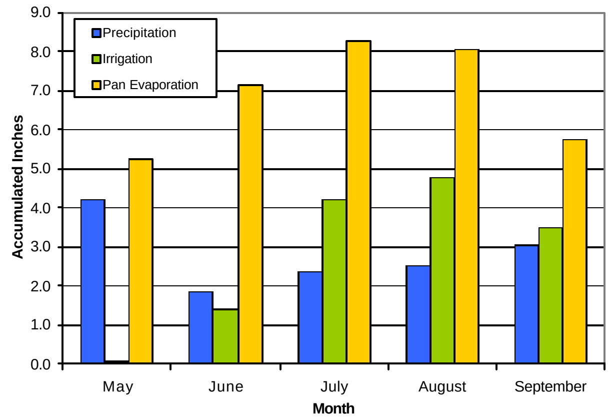

Figure 1. Accumulated irrigation, precipitation and pan evaporation on a monthly basis during the 2006 growing season.

An AgLeader PF3000 cotton yield monitoring system was used to determine cotton performance. The accumulated amount harvested from each plot was also weighed. A quality analysis was conducted by harvesting 50 cotton bolls collected at three locations within each plot (48 total samples; 3 locations X 16 plots). Quality factors considered were micronaire, strength, leaf grade, uniformity, and length. Differences existed between all quality features except for Leaf Grade. Yield and quality data were analyzed using LSD T-tests to determine if any significant differences existed between treatments.

TIR collected included collecting ground truth data coincident with remotely sensed TIR data acquisition to quantify differences in plant, soil, and residue attributes contributing to measured emittance, as well as, to directly verify the relationship between canopy response and emittance. Six sample locations along the length of each plot were identified and marked using a RTK survey grade GPS unit. Ground truth consisted of soil water content, stomatal conductance, and digital photographs. Thermal infrared data were collected using an unmanned aerial vehicle (UAV) equipped with a TIR sensor (L3 Communications Infrared Products, Dallas, TX). The TIR system consisted of a lightweight (145 g) camera with a thermal sensitivity of =100mK. The focal plane array (160 x 120 pixels) for the camera consisted of an uncooled, amorphous silicon microbolometer. The system records emittance (7–14 µm) as a digital value ranging from 0-255, with increasing emittance represented by increasing digital value. TIR infrared data was acquired on 18 July 2006, at 10:13 AM central standard time, under clear conditions. The cotton was between 1st and peak flower with a percent canopy ranging from 15% to 72%. Collected data was saved in a TIFF file format and imported into ERDAS Image 8.7 for clipping, geo-registration and data extraction. Statistical Analysis System (SAS Inst., NC) was to determine the relationship between TIR emittance, stomatal conductance, soil water content or plant available water, crop residue management, and vegetative fraction (canopy closure).

Results and Discussion

Yield results from the four treatments had significant differences (Table 1). There were, as was expected, significant differences between irrigated and non-irrigated plots yields. Yields on irrigated plots were as high as 61% higher than the yields measured on non-irrigated plots. There were also differences for the cover crop vs. no cover crop comparison, with those of the irrigated cotton having significantly higher yields. Yields for the plots receiving a cover crop treatment were as much as 16% higher than the plots without a cover crop. The trend appears to be that cover crops are providing yield benefits. This yield response could be a result of increased organic matter (OM) for the cover crop plots over the past 3 years potentially providing increased soil water holding capacity and reduce surface water evaporation.

Table 1. 2006 cotton yield averages for each treatment.

Treatment	**Yield - Seed Cotton (lbs/ac)***
Irrigated / Cover	2853 [a]
Irrigated / No Cover	2396 [b]
Non-Irrigated / Cover	1098 [c]
Non-Irrigated / No Cover	941 [c]

* Mean yields with similar letters indicate they are not statistically different at the 90% confidence level.

The cotton quality analyses indicated that for Micronaire, the irrigation-cover crop treatments were significantly higher than the other treatments. Irrigated plots had significantly higher lint strengths than on the non-irrigated plots. The non-irrigated plot with cover also had significantly higher lint strength than the non-irrigated plot without a cover crop. Lint uniformity was significantly higher on irrigated plots with a cover crop. Uniformity was also significantly higher for the plots with irrigation and no cover crop compared to both non-irrigated treatments. The lint length was significantly longer on all irrigated treatments than on the non-irrigated treatments.

Table 2. Cotton quality averages per treatment.

Treatment	**Micronaire*[1]**	**Strength (g/Tex)***	**Uniformity (%)***	**Length (in)***
Irrigated / Cover	4.4 [a]	28.5 [a]	83.5 [a]	1.1 [a]
Irrigated / No Cover	3.9 [b]	28.0 [a]	82.8 [b]	1.1 [a]
Non-Irrigated / Cover	4.1 [b]	26.1 [b]	81.8 [c]	1.0 [b]
Non-Irrigated / No Cover	4.1 [b]	25.2 [c]	81.2 [c]	1.0 [b]

* Mean yields with similar letters indicate they are not statistically different at the 90% confidence level.
[1] Values between 3.5 and 4.9 are not discounted at the gin.

Another result discovered during 2006 for this project was that using 60% of calculated pan evaporation (adjusted for % canopy closure) for scheduling irrigation was not sufficient during drought conditions. Visual assessment of the cotton during the growing season showed less vegetation and boll development when compared to other ongoing irrigation studies at TVREC. Final yields between this project and the other studies also supported these in-season observations. Therefore, 60% pan did not supply sufficient water during irrigation events to maximize cotton yields for the dry growing conditions experiences in 2006. Based on these results, 90% has been selected for future use to schedule irrigation for this project.

Due to the integrated effect of surface characteristics (canopy closure, % actively transpiring vegetation, crop residue cover and bare soil) impacts observed emittance (digital values), variability in surface characteristics at the time of TIR acquisition were evaluated (Table 1). It was necessary to log transform stomatal conductance and canopy cover to normalize the dataset prior to analysis of variance (ANOVA). No differences in soil water content were observed between treatments. However, significant differences in canopy closure were noted across irrigation as well as cover treatments. No significant interaction between treatments was observed. The impact of irrigation management on canopy closure was most significant having 40% canopy closure on irrigated treatments and 26% canopy closure on non-irrigated treatments. Differences in canopy closure between covered and no-covered treatments were less significant, but showed greater canopy closure on cover treatments compared to no-cover treatments.

Table 1. Soil water content, canopy closure, crop residue cover and stomatal conductance reported for significant treatment effects. Interactions between treatments are denoted by "x".

--------------------Treatment--------------------			Stomatal Conductance	Soil Water Content	Thermal Infrared	Canopy Closure	Crop Residue Cover
Irrigation	**x**	**Cover**	**mmols m^{-2} s^{-1}**	**cm^3 cm^{-3}**	**D.V.**	**%**	**%**
Irrigated			6.09 A	NS‡	94.6 B	3.65 A	
Dryland			5.36 B	NS	157.2 A	3.24 B	
LSD			**0.30**		24.1	0.11	
		Cover		NS	114.7 B	3.53 A	
		No Cover		NS	143.9 A	3.36 B	
		LSD			**23.9**	**0.1**	
Irrigated		Cover					24.4 A
Irrigated		No Cover					27.7 A
LSD							**3.8**
Dryland		Cover					32.7 A
Dryland		No Cover					27.5 B
LSD							**3.9**

Means followed by the same letter are not statistically different at alpha = 0.05.
† A significant interaction was observed between Irrigation and Cover treatments for estimates of residue cover only.
‡ No significant response is indicated by NS.

The relationships between observed TIR emittance and ground truth parameters were evaluated using Pearson Linear Correlation Coefficients. Of particular importance to the evaluation of the TIR system, a negative correlation between stomatal conductance and TIR emittance (r = -0.48, alpha = 0.05) provides evidence that the TIR system was related to plant transpiration. Additionally, a negative linear relationship was observed between TIR emittance and canopy closure (r = -0.44, alpha = 0.05), indicating cooler surface conditions as canopy closure increased. As transpiration rates increased, TIR emittance decreased. Although soil water content was highly correlated with stomatal conductance (r = 0.58, alpha = 0.05), no significant correlation was observed between TIR emittance and soil water content.

Collected TIR imagery was able to identify some SDI issues. One image acquired over the north-eastern quadrant of the field indicated the existence of two crimped SDI lines within irrigation plots and an area were distribution issues existed (Figure 2). The crimped lines are evident, spanning the length of the image as a very bright feature within two irrigated treatments. Comparing the area along either side of the crimped lines with adjacent rows of well-watered cotton, emittance was more than two times greater along the crimped lines. Based on the evaluation of the TIR system, this represents an area where cotton plants are not actively transpiring and exhibiting signs of water stress. The distribution issues are evident as an area of very bright surface features (canopy stress), bounded on either side by dark surface features (actively transpiring canopy). Yield monitor data indicated yield losses up to 35% due to the crimped SDI tape. However, results suggest that SDI problems can be rapidly and easily identified using the UAV and TIR imagery allowing such issues to be corrected in a timely fashion during the growing to minimize yield loss.

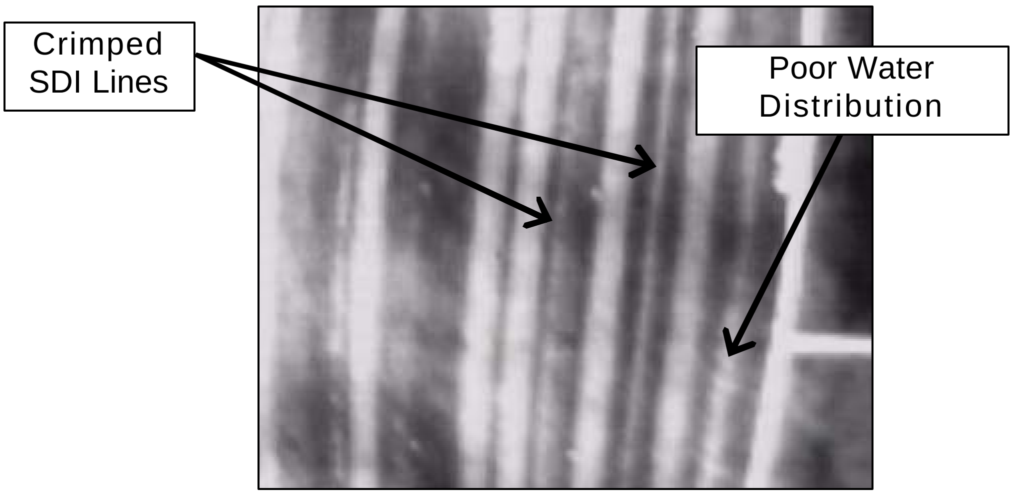

Figure 2. Thermal infrared image showing crimped SDI tape and an area of poor water distribution.

Conclusion

Irrigated treatments had significantly higher yields along with the cover crop treatments. Cover crop treatments tended to be higher yielding. For the quality data the difference that was noted repeatedly, and was significant, was that micronaire, lint strength, lint uniformity, and lint length are all significantly higher on irrigated plots than on non-irrigated plots. Remote-sensed thermal imagery was also collected during the 2006 growing season. Emittance spectra were also highly correlated with stomatal conductance (r = -0.48, alpha = 0.05), providing evidence that observed emittance was related to variability in canopy response to irrigation and cover treatments. More importantly, the UAV observations more accurately differentiated between relative differences in canopy response to irrigation and crop residue cover management compared to ground measurements of stomatal conductance, which were time and labor intensive. TIR was capable of identifying SDI tape issues. In conclusion, preliminary results indicated that high resolution thermal imagery may prove to be very useful in identifying in-season SDI issues and provide a management tool for SDI.

References

Barnes, E.M., T.R. Clarke, S.E. Richards, P.D. Colaizzi, J. Huberland, M. Kostrzewski, C. Choi, E. Riley, T. Thompson, R.J. Lascano, H. Li, and M.S. Moran. 2000. In Proc. 5th International Conference on Precision Agriculture. ASA-CSSA-SSSA, Madison, WI.

Campbell, G.S. 1977. An introduction to environmental biophysics. Springer Verlag, New York.

Cline, R.G. and G.S. Campbell. 1976. Seasonal and diurnal water relations of selected forest species. Ecology. 57:367-373.

Colwell, R.M. 1956. Determining the prevalence of certain cereal crop diseases by means of aerial photography. Hilgardia. 26:223-286.

Fulton, J.P., M. Dougherty, L.M. Curtis, H.D. Harkins, C.H. Burmester. 2005. Subsurface Drip Irrigation (SDI) Scheduling and Tape Placement for Cotton Production in Alabama. ASAE Paper No. 052244. Annual International Meeting, Tampa Convention Center, Tampa, Florida, July 17-20.

Herwitz, S.R., L.F. Johnson, J.C. Arvesen, R.G. Higgins, J.G. Leung, and S.E. Dunagen. 2002. Precision agriculture as a commercial application for solar-powered unmanned aerial vehicles. In Proc. AIAA's 1st Technical Conference and Workshop on Unmanned Aerial Vehicles, Portsmouth, VA. 20-23 May 2002.

Penuelas, J. I. Filella, C. Biel, L. Serrano, and R. Save. 1993. The reflectance at the 950-970 nm region as an indicator of plant water status. Int J. Remote Sens. 14:1887-1905.

Sadler, J.E., C.R. Camp, D.E. Evans, and J.A. Millen. 2002. Corn canopy temperatures measured with a moving infrared thermometer array. Trans. ASAE 45:581-591.

Shannahan, J.F., J.S. Schepers, D.D. Francis, G.E. Varvel, W.W. Wilhelm, J.M. Tringe, M.R. Schlemmer, and D.J. Major. 2001. Use of remote sensing imagery to estimate corn grain yield. Agron. J. 93: 583-589.

Simpson, A., T. Stombaugh, L. Wells, and J. Jacob. 2003. Imaging techniques and applications for UAV's in agriculture. In Proc. ASAE Annual International Meeting, Las Vegas, NV. 27-30 July 2003.