ARE THERMAL IMAGES ADEQUATE FOR IRRIGATION MANAGEMENT?

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ABSTRACT

Thermal crop sensing technologies have potential as tools for monitoring and mapping crop water status, improving water use efficiency and precisely managing irrigation. Leaf Water Potential (LWP) measurements by pressure bomb in the boll-filling stage of cotton is currently used as an effective tool for irrigation management. Nevertheless, these measurements do not express the variability in the field. Estimation of LWP from thermal images could address this problem. In previous studies, a regression model for assessing LWP in cotton plants based on crop water stress index calculated using ground and airborne thermal imagery was developed and validated. In this study we applied this model and compared between thermal-based irrigation management and today's common practice. The experimental results show that there is no significant differences between the methods and that cotton can be irrigate efficiently using LWP values that are derived from remotely sensed thermal images. The thermal-based method resulted to similar seasonal water application amounts as the commercial practice, and achieved yields that were slightly higher but with no statistically significant difference from commercial practice (n=6, p=0.01). For its assimilation the cost effectiveness of the thermal-based irrigation management should be examined in commercial scales. Future study should focus on the applicability of this approach for variable rate irrigation.

Keywords: Cotton, Thermal images, CWSI, Irrigation management, Leaf water potential,

INTRODUCTION

Cotton is an important and high value crop. Cotton yield and quality are highly dependent on an adequate supply of water. Thermal crop sensing technologies have potential as tools for monitoring and mapping crop water status, improving water use efficiency and precisely managing irrigation. As thermal sensors and imagers became more affordable, various platforms were examined to allow for canopy- and field-scale acquisitions of canopy temperature and to extract maps of water status variability(Gonzalez-Dugo et al., 2013). Various canopy temperature statistics and crop water stress index (CWSI) were used to estimate water status in different field and orchard crops (Agam et al., 2013; Fuentes et al., 2012). Despite the potential reflected from these studies, currently, thermally-based water status measures and maps are scarcely utilized for irrigation management.

Currently, the best practice to assess water status in commercial cotton fields in the boll-filling stage, is to measure leaf water potential (LWP) of few selected plants. These measurements do not necessarily represent the entire field or its variability. Despite its proven efficiency the LWP-based irrigation management is not the common practice because of its complication.

In the current study thermal-based irrigation management was compared with a commercial practice in cotton.

MATERIALS AND METHODS

Field plots:

Field measurements were conducted in the summer of 2013 at Kibutz Givat Brener, Israel. Experimental plots were planted with cotton *Gossypium hirsutum x Gossypium barbadense hybrid* ("Acalpi") and were drip-irrigated with one lateral between every two rows. Each plot was 18 m wide by 19 m long. The plots were treated with two different practices in six replicates, for a total of 12 plots: 1) commercial irrigation management based on few direct LWP measurements conducted twice a week; 2) thermal-based irrigation management based on LWP values estimated from thermal images acquired once a week.

Image acquisition:

Oblique thermal images were acquired above the experimental plots using uncooled infrared thermal cameras (SC655 and SC2000, FLIR systems, Oregon, USA). The SC655 camera has 640X480 pixels, is sensitive in the spectral range of 7.5 - 13µm and has a measurement accuracy of ±2ºC. The SC2000 camera has the same specifications as SC655 except the resolution, which is 320X240 pixels. The images where acquired from a platform 20m above the ground that was mounted on a tractor. The spatial resolution of the thermal images acquired by SC655 ranged from 0.028 to 0.075 m per pixel for the closer plots and the last plots in the image respectively. However, the spatial resolution of the thermal images acquired by SC2000 ranged from 0.075 to 0.165 m per pixel for the closer plots and the last plots in the image respectively. Image acquisition was carried out during the summer of 2013 on four days in the boll filling period 04/08/13, 11/08/13, 18/08/13, and 25/08/13. At 11/08/13 an airborne thermal image was acquired, from an altitude of about 500 m, with a spatial resolution of 0.35 m. The thermal images were acquired just before irrigation.

Leaf samples:

Six leaves from each plot were sampled and their LWP was measured with a pressure chamber (model ARIMAD 1, Mevo Hama Instruments, Israel), as described by (Meron et al., 1987). The youngest fully expanded leaf below the main stem terminal was chosen. Each leaf was wrapped in aluminum foil, cut and put in a plastic box with wet paper and measured in the pressure chamber. The measurements were conducted around the time of solar zenith (11:00 – 15:00 local time, daylight saving IST (Israel Standard Time), which was GMT +3). On each date, LWP was measured in 12 plots.

Meteorological conditions:

Air temperature, relative humidity, global radiation and wind speed were measured by a meteorological station located within the experimental plot. The sampling rate was every 10 s (excluding wind - every 1 s), and 1-min averages were recorded by a data logger (Campbell Scientific, Logan, UT, USA). Meteorological conditions were measured throughout all hours of data collection.

CWSI:

CWSI is defined as follows (Idso et al., 1981):

$$1. \quad \mathrm{CWSI} = \frac{Tl - Twet}{Tdry - Twet}$$

where *Tl* is leaf or canopy temperature, and *Twet* and *Tdry* are the minimum and maximum boundary temperatures, respectively. The maximum and minimum boundary temperatures can be derived empirically, theoretically or statistically (Cohen et al., 2005; Jones, 1999; Meron et al., 2010). In this study, *Tdry* was used only in its empirical form, i.e. *Tair*+5°*C* as it was found to be a suitable estimate of the maximum leaf temperature for various crops (Alchanatis et al., 2010; Ben-Gal et al., 2009; Moller et al., 2007). *Twet* was calculated in two forms. For the ground platform thermal images *Twet* was calculated using a plant reference: a well-watered strip was maintained in the field and its canopy temperature was extracted from the thermal image and assigned to *Twet*.

The *Twet* for the airborne thermal images was calculated using a virtual reference: *Twet* was determined as the mean of the lower 5th percentile of the canopy temperature in the whole experimental field. In this approach, it is assumed that certain areas in the field are well-irrigated or suffer from over-irrigation (Alchanatis et al., 2010; Holland et al., 2011).

Processing of thermal images:

Three steps were required to calculate LWP using thermal images. First, average canopy temperature was extracted for each replicate-plot. Separation between vegetation and background was done following (Meron et al., 2010):

$$2.\quad Tair - 10°\mathrm{C} < TI < Tair + 7°\mathrm{C}$$

where *Tair* is the air temperature as measured at the time of the thermal image acquisition. For each plot, the mean canopy temperature was extracted and used as *Tl*. Secondly, CWSI was calculated using the average canopy temperature, *TI*, and two reference temperature values: *Twet* and *Tdry*. Finally, LWP was calculated using the linear CWSI-LWP model that was built in previous years by (Sela, 2007):

$$3.\quad \mathrm{LWP} = -1.7622CWSI - 1.2724$$

RESULT AND DISCUSSION

The estimated LWP for all four days was compared to the measured LWP. Figure 1 shows the standard errors between the measured and the calculated values for each day.

Figures 2 presents the seasonal irrigation amounts for the two irrigation management methods. Until day 30 from onset (21/07/2013) the entire field receives homogeneous irrigation of 325 mm. From day 31 from onset until the

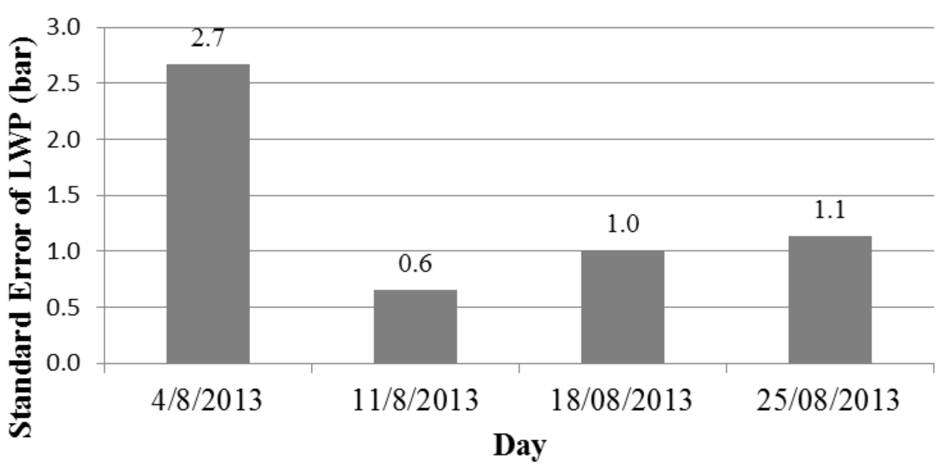

Figure 1. Standard error between measured and calculated LWP .

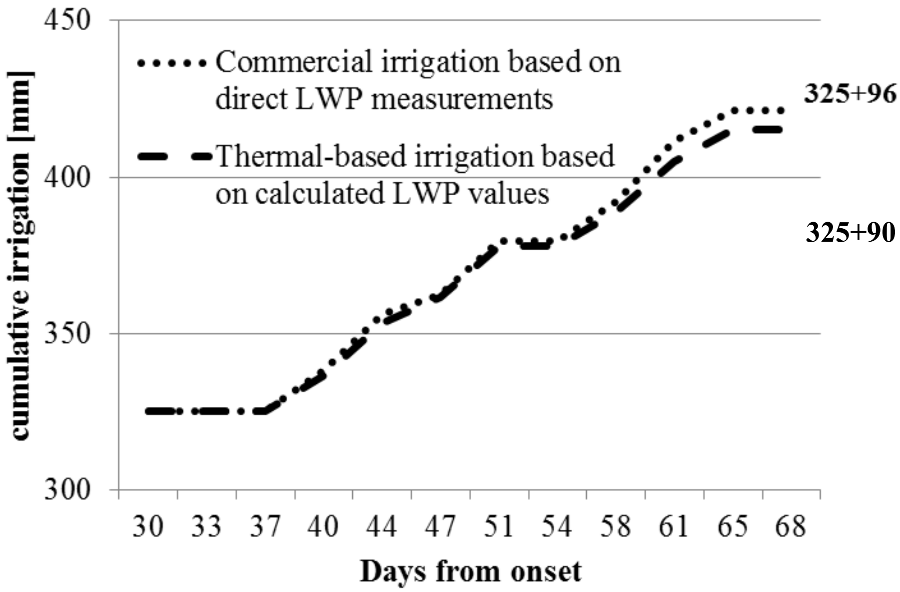

Figure 2. Seasonal cumulative water application for the two management methods. Until day 30 from onset (21/07/2013), all the field received the same amount of 325 mm. From day 31, the irrigation was separate and determined by direct LWP measurements or by calculated LWP from the thermal image.

end of the boll filling stage, commercial irrigation that was based on direct LWP measurements received 96 mm and the thermal based irrigation, based on calculated LWP values, received 90 mm. The seasonal cumulative irrigation was 421 mm and 415 mm for the commercial irrigation and thermal based irrigation respectively.

The experimental results show that irrigation management based on thermal images in the boll-filling stage results to yields that are comparable to the current common practice. Moreover, the results show that thermal images provide reliable information about the plant water status, as compared with measurements using a pressure bomb. The standard error of the image estimated LWP ranged from 0.6 bar to 2.7 bar (Figure 1). These values are within the expected error of the CWSI – LWP model, which is reported to be 2.6 bar (Sela, 2007). The lowest estimation error was observed on 11/08/13 (standard error 0.6 bar), which corresponds to the day that the images were acquired from an airborne platform.

The cumulative irrigation amounts that are presented in Figure 2 show that cumulative water application over the entire season using thermal images was similar to the conventionally derived water application. The difference between the two methods was 6 mm.

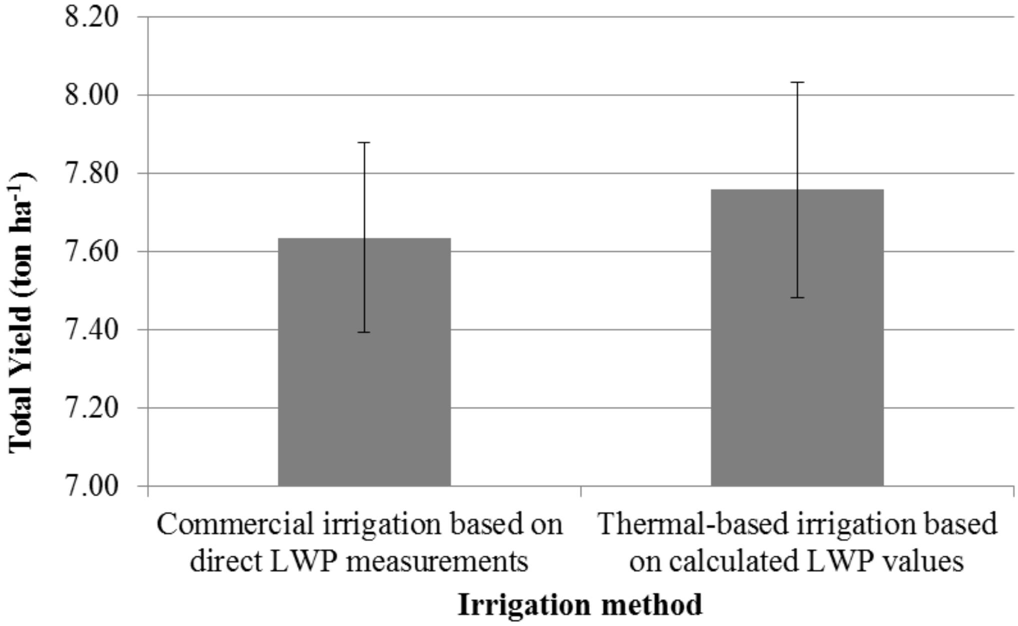

Figure 3. Average yield of the two irrigation management methods Error bars represent standard error of replicates (n=6).

Figure 3 presents the average yield for each irrigation management method. The average yield was 7.63 ton ha^{-1} and 7.76 ton ha^{-1} for the commercial and the thermal based method respectively. Although the yield obtained by the thermal-based management was slightly higher, there was no statistically significant difference between the two methods (n=6, p=0.01). Assuming that the commercial management of the experimental plots corresponds to the best obtainable yield, the results of the present work imply that remotely sensed thermal data can replace direct pressure bomb measurements, while maintaining at least the same yield level and similar amounts of water application.

The presented methodology can be applied to entire fields, and provide the average LWP value of each irrigated area. Figure 4 shows the LWP map of a commercial field where one average value is depicted for each irrigated plot. The aerial thermal image was acquired the day before irrigation and average canopy temperature was calculated for each irrigated area. Using the CWSI-LWP model, an average value of LWP was assigned to each area. Although the entire field was supposed to be in the same water status, differences are observed between the different areas. In most of the areas the differences are small and range between well irrigated and over irrigated levels. The most notable difference is between the northern section and the rest of the field. While most of sections are well-watered and over irrigated, the northern section suffers from medium water stress. This map demonstrates the advantage of using water status mapping using thermal images over the current practice of pressure bomb measurements of 6 leaves in two pre-defined sites in the field for irrigation decision making.

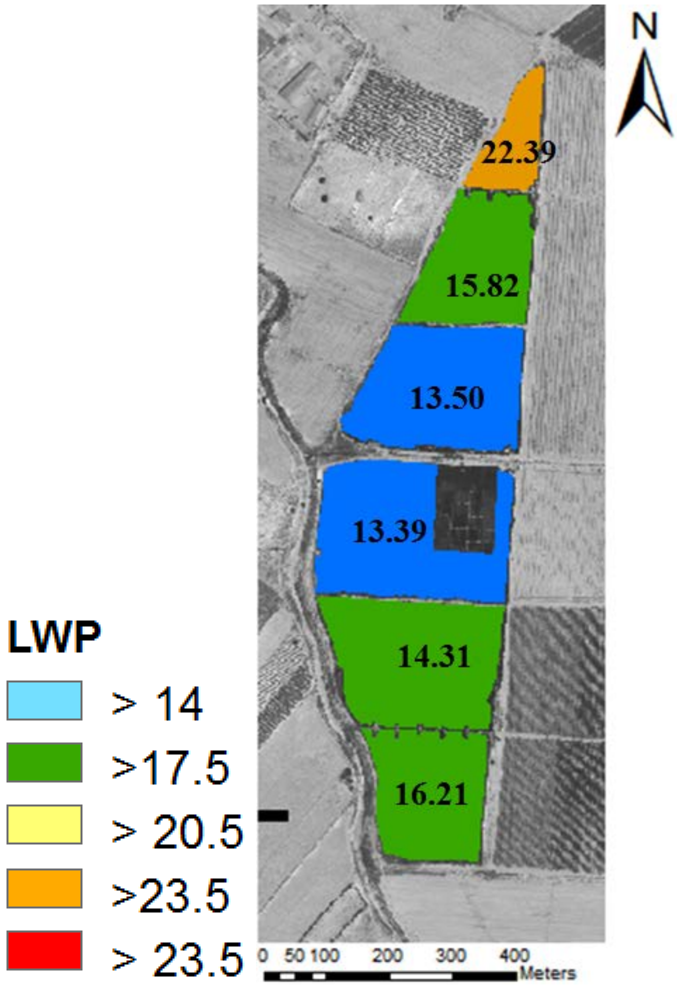

Figure 4. LWP map of a commercial field on 10/07/2011. The numbers on each section represent the average LWP of the section in bar.

CONCLUSIONS

The results of this study showed that remotely sensed thermal images can be used for irrigation management in cotton. For its assimilation the cost effectiveness of the thermal-based irrigation management should be examined in commercial scales. Future study should focus on the applicability of this approach for variable rate irrigation.

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