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# Estimating Light Interception by Cotton Using a Digital Imaging Technique

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## ABSTRACT

Radiation intercepted by the crop canopy is directly correlated to dry matter accumulation. Calculation of fractional light interception by the crop is commonly performed by measuring photosynthetically active radiation above and below the canopy using a line-source quantum sensor. However, this method is limited by the time of measurement and the presence of clouds. For soybeans grown in 19-cm rows, ground coverage values estimated from digital images taken above the canopy have been correlated to light interception measurements, but there have been no reports of using this method in cotton or in other crops on wide rows. In this study, a digital imaging technique was used to establish a relationship between fractional canopy coverage and fractional light interception for cotton. This study suggests that digital imaging may be used as an alternative technique for estimating light interception by cotton.

*Keywords: Canopy coverage; cotton; digital imaging; light interception.*

## 1. INTRODUCTION

Solar radiation is the energy input that drives photosynthesis and the production of organic molecules by plants. Accumulation of dry matter by a crop is directly dependent upon the amount of radiation intercepted by the crop canopy (Monteith, 1977). However,

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measurements of the ability of the canopy to intercept radiation are rarely presented in scientific manuscripts to describe canopy dynamics for treatment comparison.

Fractional light interception (LI) by the canopy can be estimated from an analog of Beer's law as described by Monsi and Saeki (1953):

$$LI = 1 - \exp^{-k \times LAI} \quad (1)$$

Where  $k$  is the canopy extinction coefficient and LAI the leaf area index. The extinction coefficient  $k$  depends upon the angle distribution of the leaves in the canopy and the angle of radiation (zenith solar angle) and has been reported to be specific to crop type and stage of development (Gourdiaan, 1988).

The most common method of measuring the fraction of radiation intercepted by the crop canopy is using a line-source quantum sensor (Rosenthal and Gerik, 1991; Heitholt, 1994; Sadras and Wilson, 1997; Kiniry et al., 2005). In this technique photosynthetically active radiation (PAR) is measured above and below the canopy and the LI is calculated by the equation:

$$LI = 1 - (I / I_0) \quad (2)$$

Where  $I$  is the PAR below the canopy and  $I_0$  is the radiation above the canopy (incident radiation). The method is limited because measurements need to be taken in unobstructed sunlight, close to solar noon (Board et al., 1992; Egli, 1994).

Purcell (2000) described a method for estimating light interception in soybean [*Glycine max* L. (Merr.)] that was not affected by the above limitations. In this study, fractional canopy coverage was determined by digital images taken above the canopy, assuming little or no transmittance through leaves and that the angle of light is similar to the camera angle. The canopy coverage values were similar throughout the day, and were correlated in a one-to-one relationship with light interception measurements made with a line quantum sensor at solar noon (Purcell, 2000). This technique has also been used in wheat (*Triticumaestivum* L.) (Caviglia et al., 2003) and corn (*Zea mays* L.) (Edwards et al., 2005).

Digital imaging techniques have been used by researchers to describe crop canopies. Ground coverage percentage of turfgrass [bermudagrass (*Cynodondactylon* L.)] (Richardson et al., 2001) and wheat (Lukina et al., 1999) was estimated from digital images taken above the canopy. In addition, canopy coverage values have been correlated with leaf area index (LAI) for oilseed rape (*Brassica napus* L.) (Behrens and Diepenbrock, 2006). Similarly for cotton (*Gossypiumhirsutum* L.), measurement of canopy coverage with digital imaging was used to estimate LAI over a low range of LAI (Stewart et al., 2007). The same authors described the values obtained by the digital image analysis method as an estimate of light interception ability of the canopy, although no light interception measurements were recorded. In this study the digital imaging technique described for soybean by Purcell (2000) for estimating light interception by the crop canopy was tested for use in cotton.

## 2. MATERIALS AND METHODS

Data were collected from four cotton studies, across two years (2006 and 2007) and two locations [Fayetteville, AR (36° 4' N, 94° 9' W) and Marianna, AR (34° 5' N, 90° 5' W)]. A

range of plant populations and PGR experiments was used to provide differing plant canopies for the evaluation. The studies included treatments of plant populations (5 and 10 plants/m<sup>2</sup>), application of plant growth regulators [Pix Plus<sup>®</sup> (1,1-dimethylpiperidinium) (BASF Corporation, Research Triangle Park, NC) and Chaperone<sup>®</sup> (sodium 5-nitroguaiacolate, sodium o-nitrophenolate and sodium p-nitrophenolate) (Asahi Chemical Manufacturing Co., LTD, Osaka, Japan)] and leaf morphology (normal- and okra-leaf isolines). Details of the studies are presented in Table 1. The experimental plots were four rows wide (width between rows 1m) by 15 m long. The fertilization program was determined according to pre-season soil tests and recommended rates. Weed control was performed according to state recommendations, and furrow irrigation was applied as needed.

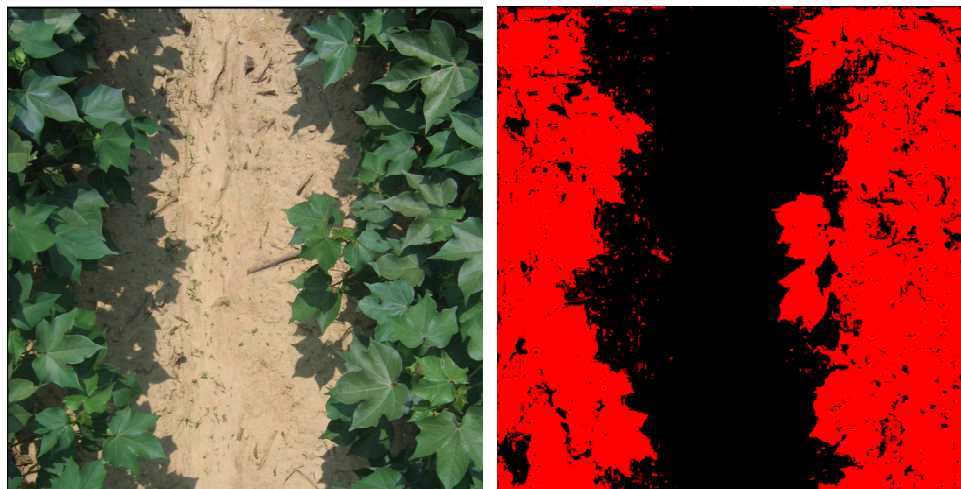
**Table 1: Details of the studies used for data collection**

Year	Location	Cultivar	Treatments
2006	Marianna, AR	DP444 BR	Plant populations
2006	Fayetteville, AR	DP444 BR	Plant growth regulators
2007	Fayetteville, AR	FM832	Plant populations Leaf morphology
2007	Fayetteville, AR	DP444 BR	Plant growth regulators

The fraction of intercepted radiation was determined by measuring photosynthetically active radiation above and below the canopy in unobstructed sunlight, close to solar noon, using a LI-191S line-source quantum sensor (Li-Cor, Lincoln, NE). Three measurements were recorded for each plot, values were averaged and the fraction of intercepted radiation was calculated by equation 2.

Following the light interception measurements, digital images were taken above the cotton crop canopy from the center of each plot with a Canon PowerShot A95 (Canon USA Inc., Lake Success, NY) digital camera mounted on a pole. The camera mount, was inclined by 30° to prevent the pole from being included in the image. By adjusting the height of the camera above the ground, the width of the image at ground level was set at 1 m. Digital images were stored as JPEG (Joint Photographic Experts Group) files with resolution of 1600×1200 pixels.

The SigmaScan Pro 5.0 software (v. 4.0, SPSS, Inc., Chicago, IL) was used to analyze the images. After the user selected hue and saturation values, the software detected the canopy (green tones) pixels of the digital image. The number of green pixels divided by the total number of pixels for each image was defined as the fractional canopy coverage. Digital images recorded at the same day or time of day were arranged in groups and analyzed in batch by the macro developed by Karcher and Richardson (2005). Figure 1 provides an example of the range of colors selected by the software and how differences were distinguished between shadows and leaves.



**Fig. 1: An example of the digital image of a cotton crop (left) and the image analyzed using the SigmaScan Pro 5.0 software (right) showing the colors selected by the software allowing differentiation between the leaves and the shadows.**

Measurements were recorded every seven to ten days between the pinhead square stage of growth and three weeks after flowering. A total of 230 images were analyzed and the ground coverage values were plotted against the fractional intercepted radiation measurements made with the line-source quantum sensor.

On July 17, 2007 digital images were taken every two hours between 9:00 a.m. and 5:00 p.m. from 20 plots in Fayetteville, AR. In addition, digital images were recorded from eight plots in unobstructed sunlight and also in the presence of passing clouds.

The statistical analysis was performed with the JMP 6 software (SAS Institute Inc., Cary, NC). Statistical differences were detected using Student's t-test. Data means were separated at probability values  $\alpha \leq 0.05$ . Regression analysis was used to determine the relationship between light interception and canopy coverage.

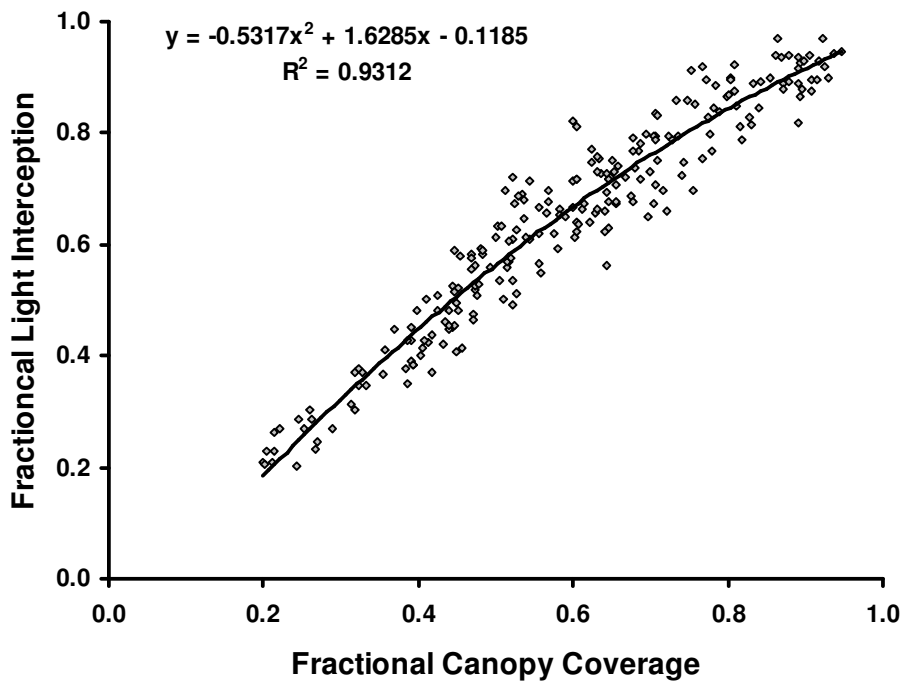
### 3. RESULTS AND DISCUSSION

Cotton canopy fractional light interception (LI) values were highly correlated ( $r^2=0.96$ ,  $P=0.0001$ ) with fractional canopy coverage (CC) values estimated by the digital imaging software (Fig. 2). The two measurements were found to follow a quadratic relationship described by the equation:

$$LI = -0.5317 \times CC^2 + 1.6285 \times CC - 0.1185 \quad (3)$$

Previous research evaluating canopy coverage measurements with fractional light interception found a 1-to-1 relationship in soybean (Purcell, 2000). The reason(s) for the quadratic relationship in the present research is not known. With soybean, Purcell (2000)

originally established this 1-to-1 relationship with soybean grown on 19-cm rows. Subsequent research by De Bruin and Pedersen (2009) with soybean grown on 38-cm rows also found a 1-to-1 relationship between canopy coverage and fractional light interception. The 100-cm row spacing used in the present research with cotton may be a factor contributing to the non-linearity shown in Figure 1. Although a quadratic relationship was statistically significant ( $P < 0.0001$ ), the difference between the quadratic regression line and a 1-to-1 relationship differed by less than 7% over the entire range of values. The difference between the canopy coverage values and the fractional light interception values may be due to the limited area sampled by a line-quantum sensor. The area sampled the digital image was approximately 1 m<sup>2</sup> compared to approximately 0.03 m<sup>2</sup> for the line quantum sensor (1 m x 0.01 m x 3 measurements). Additional research would be required to characterize potential limitations to the digital-imaging method.



**Fig. 2: Relationship between light interception and canopy coverage.**

Canopy coverage values estimated from digital images did not significantly ( $P=0.623$ ) differ between time that the images were recorded (Fig. 3). In contrast to light interception measurements made with a line-source quantum sensor, that are limited only close to solar noon, the digital imaging technique can be used at any time of the day.

Cotton crop canopy images were recorded in unobstructed sunlight and in the presence of passing clouds. The canopy coverage values estimated by these images were not significantly ( $P=0.836$ ) different (Fig. 4). Therefore, the digital imaging technique is not limited by days with unobstructed sunlight.

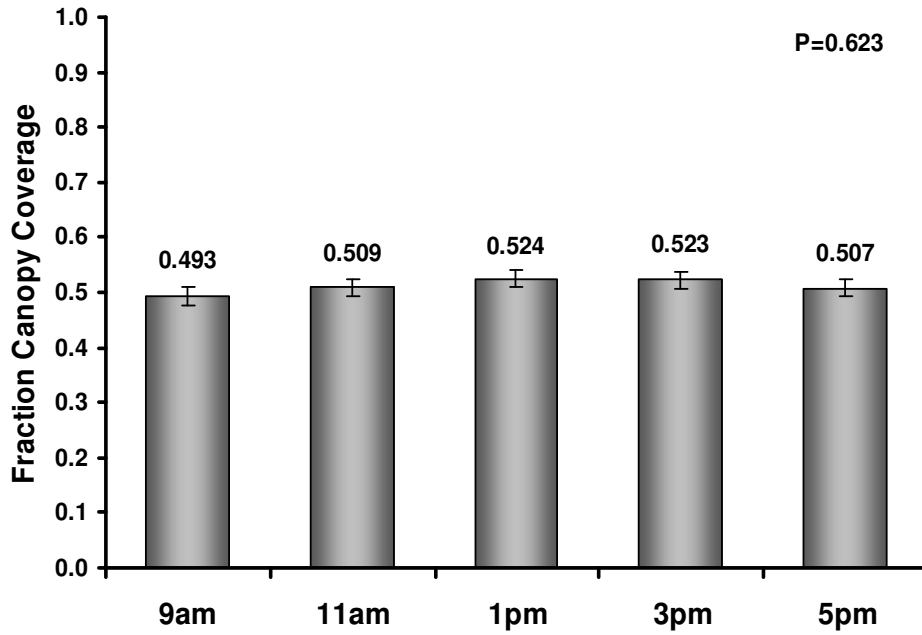


Fig.3: Canopy coverage estimates from digital images taken every two hours in unobstructed sunlight ( $\pm 1$  std. error bars are shown).

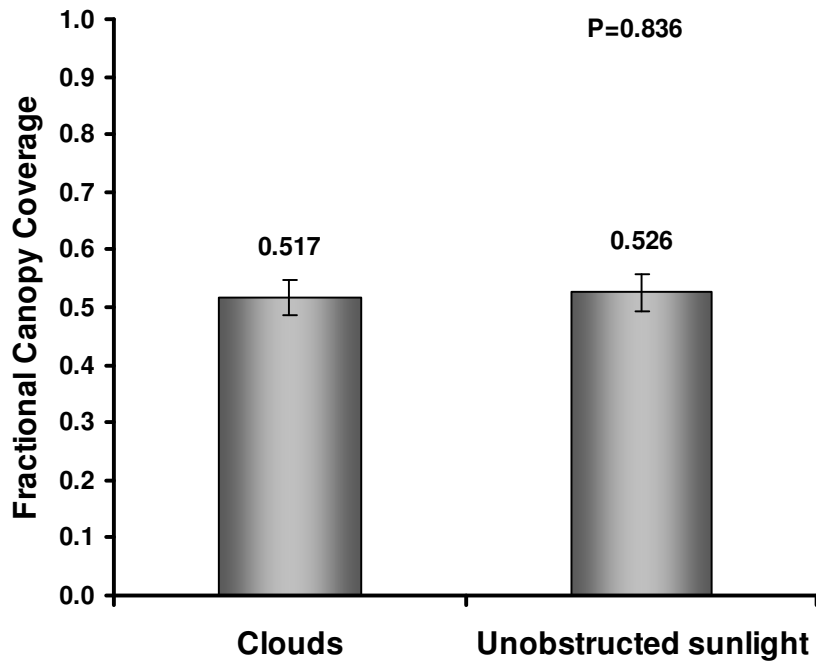


Fig. 4: Canopy coverage estimates from digital images taken at the presence of passing clouds and in unobstructed sunlight ( $\pm 1$  std. error bars are shown).

The ability of a crop to intercept solar radiation is rarely presented in scientific manuscripts due to the effort and time necessary to record this measurement when a line-source quantum sensor is used. However, digital imaging techniques, as described by Purcell (2000) for soybean, provide a simpler method to estimate light interception by the crop canopy. This study suggests that the imaging technique can be used in cotton, with canopy coverage values, estimated by digital images recorded above the canopy, being highly correlated to light interception measurements. Limitations of recording light interception with a line-source quantum sensor were shown not to be a factor with the use of the digital imaging technique in cotton.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

## REFERENCES

- Behrens, T., Diepenbrock, W. (2006). Using digital image analysis to describe canopies of winter oilseed rape (*Brassica napus* L.) during vegetative developmental stages. *J. Agron. Crop Sci.*, 192, 295-302.
- Board, J.E. et al. (1992). Temporal importance of greater light interception to increase yield in narrow-row soybean. *Agron. J.*, 84, 575-579.
- Caviglia, O.P. et al. (2003). Intensification of agriculture in the south-eastern Pampas: I. Capture and efficiency in the use of water and radiation in double-cropped wheat-soybean. *Field Crops Res.*, 87, 117-129.
- De Bruin, J.L. et al. (2009). New and old soybean cultivar responses to plant density and intercepted light. *Crop Sci.*, 49, 2225-2232.
- Edwards, J.T. et al. (2005). Light interception and yield potential of short-season maize (*Zea mays* L.) hybrids in the midsouth. *Agron. J.*, 97, 225-234.
- Egli, D.B. (1994). Mechanisms responsible for soybean yield response to equidistant planting patterns. *Agron. J.*, 86, 1046-1049.
- Gourdiaan, J. (1988). The bare bones of leaf-angle distribution in radiation models for canopy photosynthesis and energy exchange. *Agric. For. Meteorol.*, 34, 155-169.
- Heitholt, J.J. (1994). Canopy characteristics associated with deficient and excessive cotton plant population densities. *Crop Sci.*, 34, 1291-1297.
- Karcher, D.E., Richardson, M.D. (2005). Batch analysis of digital images to evaluate turfgrass characteristics. *Crop Sci.*, 45, 1536-1539.
- Kiniry, J.R. et al. (2005). Peanut leaf area index, light interception, radiation use efficiency, and harvest index at three sites in Texas. *Field Crops Res.*, 91, 297-306.
- Lukina, E.V. et al. (1999). Estimating vegetation coverage in wheat using digital images. *J. of Plant Nutr.*, 22, 341-350.
- Monsi, M., Saeki, T. (1953). Über den Lichtfaktor in den Pflanzengesellschaften und seine Bedeutung für die Stoffproduktion. *Jpn. J. Bot.*, 14, 22-52.
- Monteith, J.L. (1977). Climate and efficiency of crop production in Britain. *Phil. Trans. R. Soc. London, B.*, 281, 277-294.
- Purcell, L.C. (2000). Soybean canopy coverage and light interception measurements using digital imagery. *Crop Sci.*, 40, 834-837.
- Richardson, M.D. et al. (2001). Quantifying turfgrass cover using digital image analysis. *Crop Sci.*, 41, 1884-1888.

- Rosenthal, W.D., Gerik, T.J. (1991). Radiation use efficiency among cotton cultivars. *Agron. J.*, 83, 655-658.
- Sadras, V.O., Wilson, L.J. (1997). Growth analysis of cotton crop infested with spider mites: I. Light interception and radiation use efficiency. *Crop Sci.*, 37, 481-491.
- Stewart, A.M. et al. (2007). Measuring canopy coverage with digital imaging. *Commun. Soil Sci. and Plant Anal.*, 38, 895-902.

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