Canopy cover is a useful way of monitoring crop productivity. Canopy photosynthesis is greatest when the crop reaches its maximum cover value because the plants are intercepting the most light and absorbing the most photosynthetic radiation (Lee, 2006; Wells, 1991). One common method for measuring canopy cover is by measuring light interception with a line quantum sensor (De Bruin and Pedersen, 2009; Hankinson et al., 2015). However, this system can be cost prohibitive and time-consuming, and measurements should be collected near solar noon (Adams and Arkin, 1977; De Bruin and Pedersen, 2009; Purcell, 2000). Another method for measuring canopy cover is fractional green canopy cover (FGCC) from pictures or videos (Patrignani and Ochsner, 2015). Canopy cover values determined by FGCC from digital pictures analyzed in SigmaScan Pro (Systat, 1998) were closely related to light interception measurements (De Bruin and Pedersen, 2009; Purcell, 2000). Purcell (2000) also noted that the amount of time to analyze the digital images was comparable to the time required for taking light interception measurements using the line quantum sensor.

A more recently developed method for measuring FGCC is Canopeo (Oklahoma State University, Stillwater, OK). Canopeo is an application for iOS (Apple) and Android (Google) mobile devices and Matlab (Mathworks, Inc.) that can rapidly analyze FGCC from pictures and videos (Patrignani and Ochsner, 2015). Canopy cover values determined by FGCC from digital pictures analyzed in SigmaScan Pro (Systat, 1998) were closely related to light interception measurements (De Bruin and Pedersen, 2009; Purcell, 2000). Purcell (2000) also noted that the amount of time to analyze the digital images was comparable to the time required for taking light interception measurements using the line quantum sensor.

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Core Ideas

- The mobile device application Canopeo can be used to measure soybean canopy cover.
- Canopeo and light interception measurements of canopy cover were linearly related.
- Canopeo was faster than measuring light interception with the line quantum sensor.

Abstract: Canopy cover is a useful way of monitoring crop productivity, but it can be time-consuming to measure using light interception. The objective of this research was to evaluate soybean [Glycine max (L.) Merr.] canopy cover measured with Canopeo, a new mobile device application, compared with the light interception method. Data were collected from a soybean planting date by relative maturity study established at three locations. Canopy cover was measured every other week throughout the growing season using pictures and videos analyzed by Canopeo and was compared with light interception measurements using a line quantum sensor. There was a linear relationship between canopy cover measured with pictures ($R^2 = 0.94$) and videos ($R^2 = 0.92$) in Canopeo and light interception. These results suggest Canopeo can be used to take pictures or videos to determine canopy cover as a viable alternative to measuring canopy cover in soybean.

Soybean Canopy Cover Measured with Canopeo Compared with Light Interception

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Abbreviations: FGCC, fractional green canopy cover; NWARS, Northwest Agricultural Research Station; OARDC, Ohio Agricultural Research and Development Center; WARS, Western Agricultural Research Station.

CANOPY COVER is a useful way of monitoring crop productivity. Canopy photosynthesis is greatest when the crop reaches its maximum cover value because the plants are intercepting the most light and absorbing the most photosynthetic radiation (Lee, 2006; Wells, 1991). One common method for measuring canopy cover is by measuring light interception with a line quantum sensor (De Bruin and Pedersen, 2009; Hankinson et al., 2015). However, this system can be cost prohibitive and time-consuming, and measurements should be collected near solar noon (Adams and Arkin, 1977; De Bruin and Pedersen, 2009; Purcell, 2000). Another method for measuring canopy cover is fractional green canopy cover (FGCC) from pictures or videos (Patrignani and Ochsner, 2015). Canopy cover values determined by FGCC from digital pictures analyzed in SigmaScan Pro (Systat, 1998) were closely related to light interception measurements (De Bruin and Pedersen, 2009; Purcell, 2000). Purcell (2000) also noted that the amount of time to analyze the digital images was comparable to the time required for taking light interception measurements using the line quantum sensor.

A more recently developed method for measuring FGCC is Canopeo (Oklahoma State University, Stillwater, OK). Canopeo is an application for iOS (Apple) and Android (Google) mobile devices and Matlab (Mathworks, Inc.) that can rapidly analyze FGCC from pictures and videos (Patrignani and Ochsner, 2015). Canopeo is an automatic color threshold (ACT) image analysis tool that analyzes pixels based on the red to green (R/G) and blue to green (B/G) color ratios and an excess green index. Patrignani and Ochsner (2015) found Canopeo to be accurate and faster at quantifying FGCC than other widely used software. Canopeo can process images 75 to 2500 times faster than SamplePoint (Booth et al., 2006) and 20 to 130 times faster than SigmaScan Pro.
calculate canopy cover as follows: 

\[
C = \left( 1 - \frac{\text{PARbelow}}{\text{PARabove}} \right) \times 100
\]

where \( C \) is the canopy cover (%), PARbelow is the photosynthetically active radiation below the canopy (\( \mu \text{mol s}^{-1} \text{m}^{-2} \)), and PARabove is the photosynthetically active radiation above the canopy (\( \mu \text{mol s}^{-1} \text{m}^{-2} \)).

The mobile device application Canopeo was used to determine the percentage canopy cover by FGCC. Pictures and videos were taken using the Canopeo app on an iPad (Apple). Three pictures per plot were taken with the iPad held at a height to capture the same two rows of soybean used for the line quantum sensor measurements. The three canopy cover values were averaged per plot. One video was collected per plot by walking the entire length of the plot from between the same two rows of soybean, holding the iPad at a height to capture two rows of soybean in the video. Each video resulted in a single canopy cover value for the entire plot. At all three locations, canopy cover was measured six times for the first planting date and five times for the second planting date throughout the growing season (\( n = 285 \)).

Percentage canopy cover based on light interception using the line quantum sensor was regressed against FGCC measurements based on pictures and videos analyzed by Canopeo. Linear regression was conducted using the Proc REG in SAS 9.4 (SAS Institute, 2011). The 95% confidence interval was used to detect differences between slope of the regressions.

**Results and Discussion**

Percentage canopy cover measurements based on pictures analyzed with Canopeo were linearly related to percentage canopy cover based on light interception measured with a line quantum sensor (\( R^2 = 0.94; p < 0.01 \)) (Fig. 1A). Percentage canopy cover measurements based on videos analyzed with Canopeo were also linearly related to percentage canopy cover based on light interception (\( R^2 = 0.92; p < 0.01 \)) (Fig. 1B). Similarly, Büchi et al. (2018) found canopy cover of cover crops using Canopeo to be correlated with visual assessments of canopy cover.

Differences in canopy cover measured using pictures and videos may be attributed to the area measured. When using videos to measure canopy cover, the entire length of the plot was analyzed. Picture and light interception measurements were from the same sampling area within each plot.

According to the 95% confidence interval, the slope associated with pictures (0.92) was significantly greater than the slope associated with videos (0.84) (Fig. 1). This indicates that percentage canopy cover based on pictures was more closely related to canopy cover based on light interception. Both slopes were significantly different than 1. Early in the growing season, the light interception method may have underestimated canopy cover. The width of the light meter is approximately 2 cm, resulting in light interception measurements from approximately 2 cm above the ground, which may not have accounted for smaller plants at the VE (emergence) or VC (unifoliolate leaves unrolled) growth stages.
Conversely, early in the growing season, Canopeo analyzed the green pixels from soybean seedlings. When canopy closure was near 100%, Canopeo may have underestimated canopy cover due to shading of the lower leaves, whereas the light interception method was not affected by shading.

Both measuring canopy cover with Canopeo and by light interception have advantages and disadvantages. Canopeo is faster at calculating a canopy cover percentage and can be easily done while in the field. It took less than 1 min to take three pictures or one video per plot. With the line quantum sensor, data collection time per plot was variable due to cloud cover. It is crucial to collect light interception measurements in full sun to minimize the effect of fluctuating ambient sunlight levels. If a cloud passed over the sun, a new ambient light level had to be collected to ensure accurate calculation of canopy cover. Canopeo can be adjusted to help fine-tune its sensitivity for defining green pixels. This feature helped to provide accurate measurements; however, very dark green plants were difficult to detect regardless of the adjustment. In contrast, the light interception method can be used regardless of plant color without adjustments.

Conclusion

There was a linear relationship between canopy cover measured with pictures and videos in Canopeo and with a line quantum sensor. The linear relationship remained constant across the three trial locations, two planting dates, and 10 cultivars through the V2 through R5 soybean growth stages, indicating the robustness of FGCC to measure soybean canopy cover using Canopeo. Pictures explained slightly more of the variation in canopy cover compared with videos. Using Canopeo to take pictures or videos to determine canopy cover is a viable alternative to measuring canopy cover using light interception methods in soybeans. Furthermore, because of the speed at which Canopeo can measure canopy cover, we recommend using Canopeo instead of light interception methods for measuring soybean canopy cover.

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