



# Variability of light interception and radiation use efficiency in maize and soybean

Jeremy W. Singer\*, David W. Meek, Thomas J. Sauer, John H. Prueger, Jerry L. Hatfield

National Laboratory for Agriculture and the Environment, 2110 University Blvd., Ames, IA 50011, USA

## ARTICLE INFO

### Article history:

Received 13 October 2010

Received in revised form 2 December 2010

Accepted 5 December 2010

### Keywords:

Cumulative intercepted photosynthetically active radiation

CI-PAR

radiation use efficiency

RUE

Relative growth rate

RGR

Reliability ratio

$k$

## ABSTRACT

Variability of light interception and its derivatives are poorly understood at the field-scale in maize (*Zea mays* L.) and soybean [*Glycine max* (L.) Merr.]. Quantifying variability can provide reliable estimates of field-scale processes and reliable methodology. A field study was conducted during the 2005 growing season in a 31 ha maize and 23 ha soybean field rotated annually near Ames, IA to measure variability of cumulatively intercepted photosynthetically active radiation (CI-PAR) and radiation use efficiency (RUE) by deploying eight line quantum sensors in each field. Cumulative mean PAR interception for soybean was  $575 \text{ MJ m}^{-2}$  ending on day of the year (DOY) 249 compared with  $687 \text{ MJ m}^{-2}$  in maize ending on DOY 244. Soybean standard error ( $s_x$ ) for a single sensor was 4.48% and with six sensors was 1.83% of the final CI-PAR. Maize  $s_x$  for a single sensor was 5.29% and with eight sensors was 1.87% of the final CI-PAR. Crop biomass was quantified weekly by collecting four  $1 \text{ m}^2$  samples. Soybean RUE using all sensors was  $1.44 \pm 0.06 \text{ g MJ PAR}^{-1}$ . The highest CI-PAR from a single sensor had RUE of 1.32 and the lowest was  $1.55 \text{ g MJ PAR}^{-1}$ . Maize RUE using all sensors was  $3.35 \pm 0.09$ . The highest CI-PAR from a single sensor had RUE of 2.87 and the lowest was  $3.70 \text{ g MJ PAR}^{-1}$ . Reliable transmitted PAR and RUE estimates are obtainable at the field-scale in maize and soybean with four and three sensors, respectively, assuming that crop biomass is accurately measured.

Published by Elsevier B.V.

## 1. Introduction

Quantifying light interception by crop canopies provides important information about canopy physiological processes, impacts microclimate and water dynamics, can be used in conjunction with crop biomass data to derive RUE estimates, and is used widely in crop growth, climate, and ecosystem productivity simulation modeling. Consequently, obtaining reliable estimates of light interception is critical to generate radiation derivatives and model output. Muchow et al. (1994) suggest using four tube solarimeters in each plot to obtain reliable estimates of radiation interception in a well-managed non-uniform sugarcane (*Saccharum officinarum*) stand. Because of the cost of radiation sensors and dataloggers to continuously record data, other more cost-effective approaches that rely on spot measurements have increased.

Monteith (1994) and Sinclair and Muchow (1999) both indicate that spot measurements typically collected around solar noon on sunny days underestimate intercepted radiation. The underestimate can be as high as 10%, as reported by Charles-Edwards and Lawn (1984). Flénet et al. (1996) reported that an east-west row ori-

entation could improve time-of-day estimates. Johnson et al. (2010) point out that sensor deployment bias also effects light interception and resulting derivatives because a single deployment method does not exist. They found that using spot measurements within 2-h of solar noon with increasing canopy leaf area index (LAI), the effect of deployment method on the fraction of intercepted radiation decreases, indicating that a universal deployment method is not as critical in canopies with high LAI. The majority of radiation interception studies have been conducted in replicated research plots where it is understood that the replicates minimize the effect of canopy variability.

Quantifying light interception at the field-scale presents additional challenges to account for canopy variability across landscape position and soil type with underlying physical and chemical differences that impact crop growth. How many radiation sensors should be deployed continuously to accurately estimate radiation interception at this scale? Lindquist et al. (2005) deployed a single line quantum sensor in an on-farm study in a maize field to estimate transmitted PAR. Arkebauer et al. (2009) deployed six line quantum sensors in two sets of three about 4–5 m apart in fields ranging in size from 47 to 65.4 ha to estimate transmitted PAR. We hypothesized that increasing the number of line quantum sensors would provide greater accuracy in estimating light interception, that incremental increases in accuracy would decline above a threshold, and that fewer sensors would be required in soybean because soybean exhibits morphological plasticity and

\* Corresponding author. Tel.: +1 515 294 5502; fax: +1 515 294 8125.

E-mail addresses: [jeremy.singer@ars.usda.gov](mailto:jeremy.singer@ars.usda.gov) (J.W. Singer), [dave.meek@ars.usda.gov](mailto:dave.meek@ars.usda.gov) (D.W. Meek), [tom.sauer@ars.usda.gov](mailto:tom.sauer@ars.usda.gov) (T.J. Sauer), [john.prueger@ars.usda.gov](mailto:john.prueger@ars.usda.gov) (J.H. Prueger), [jerry.hatfield@ars.usda.gov](mailto:jerry.hatfield@ars.usda.gov) (J.L. Hatfield).

attains peak light interception more rapidly than maize. The specific objectives of this work were to (1) quantify the number of line quantum sensors required to provide high reliability in cumulative light interception estimates and (2) quantify the variability in RUE derived from varying sensor number.

## 2. Materials and methods

This study was conducted in a 31 ha maize field and 23 ha soybean field located near Ames, IA, USA (lat. 41.96°N, long. 93.69°W, 315 m above mean sea level) during the 2005 growing season. Dominant soil series are Clarion loam (fine-loamy, mixed, superactive, mesic Typic Hapludoll), Webster silty clay loam (fine-loamy, mixed, superactive, mesic Typic Endoaquolls), Nicollet clay loam (fine-loamy, mixed, superactive, mesic Aquic Hapludolls), Canisteo silty clay loam (fine-loamy, mixed, superactive, calcareous, mesic Typic Endoaquolls), and Harps clay loam (fine-loamy, mixed, superactive, mesic Typic Calciaquolls) with slopes mostly between 0 and 3%. The maize field contained approximately 28% Webster silty clay loam, 36% clarion loam, 11% Canisteo silty clay loam, 17% Nicollet clay loam, and 8% Harps clay loam. The soybean field contained approximately 32% Webster silty clay loam, 28% clarion loam, 30% Canisteo silty clay loam, 2% Nicollet clay loam, and 8% Harps clay loam (USDA, NRCS). The field has a history of maize and soybean grown in a 2 years rotation. Fall chisel plow tillage in combination with secondary tillage in the spring was used to prepare the seedbeds for sowings. Pioneer 'Brand 35Y67' maize was sown on DOY 100 (April 10th) and Pioneer 'Brand 92M70' soybean was sown on DOY 127 (May 7th). Soybean was sown in 0.76 m row spacing with a harvest population of approximately 310,000 plants ha<sup>-1</sup>. Maize was also sown in 0.76 m wide rows with a harvest population of approximately 87,500 plants ha<sup>-1</sup>. Both crops were sown in a north–south direction.

Maize and soybean shoot biomass was collected weekly starting at the VC growth stage (Fehr and Caviness, 1977) in soybean and V2 (Hanway, 1963) in maize and continued until harvest. A total of 16 consecutive weekly biomass samples were collected in maize and soybean with one final harvest sample in each crop. All biomass samples were collected from four 1.0 m<sup>2</sup> areas (1.31 m long by 0.76 m wide) each sampling period by harvesting as much shoot biomass above the soil surface as possible. Designated biomass sampling areas were delineated after crop emergence that accounted for the field topography and did not compromise field-scale flux measurements. Within these designated areas, random samples were collected weekly. Sampling areas were not biased by previous sampling. Mean biomass from the four weekly samples was used for the analysis. Mean plant number and standard deviation for all weekly soybean samples were 31.2 ± 3.9 and mean plant number and standard deviation for corn samples was 7.9 ± 0.9. All biomass samples were dried in a forced-air oven at 80 °C until constant weight. Physiological maturity occurred on DOY 262 for soybean and DOY 244 for maize.

Incident and transmitted PAR were measured using line quantum sensors (LI-191, LI-COR, Inc., Lincoln, NE, USA<sup>1</sup>). A line quantum sensor to measure incident PAR was mounted on a tripod at 2 m in the soybean field. The incident line quantum sensor was oriented from northwest to southeast, similarly to the line quantum sensors deployed under the canopies. The maize and soybean fields were adjacent to each other. In soybean, eight line quantum sensors were aligned in an east–west array in alternating rows from northwest to southeast diagonally across one row. In maize, eight line

quantum sensors were distributed across the 31 ha field, approximately 50–75 m apart, each aligned diagonally from northwest to southeast across one row. All line quantum sensors were positioned exactly across a single row such that the sensing area of the sensor was measuring transmitted radiation across a 1 m distance between two rows. All line quantum sensors were leveled and cleaned regularly and were recently calibrated. All sensors were connected to a datalogger (21X or CR23X, Campbell Scientific, Inc., Logan, UT) and the signal recorded every 60 s and averaged every 30 min.

Output from the radiation sensors was integrated to obtain daily total incident and transmitted PAR, and these values were used to calculate intercepted PAR. Photon flux density (μmol m<sup>-2</sup> s<sup>-1</sup>) from the radiation sensors was converted to energy flux (W m<sup>-2</sup>) using the conversion of 2.35 × 10<sup>5</sup> J mol<sup>-1</sup> PAR (Campbell and Norman, 1998). Radiation transmission data were lost from two line quantum sensors in soybean because of equipment failure. Leaf area index was measured periodically non-destructively adjacent to each location where a line quantum sensor was deployed using an LAI-2000 Plant Canopy Analyzer (LI-COR, Inc.). Air temperature (HMP35, Vaisala, Helsinki, Finland) and rainfall (TR-5251 tipping bucket, Texas Electronics, Inc., Dallas, TX, USA) were measured at a weather station located in the maize field. Long-term rainfall and air temperature data (1971–2000) were available at a weather station (Ames8WSW) approximately 8 K from the field site.

The variability of CI-PAR for each crop is assessed with various analyses. Using descriptive statistics for each crop and sampling date the standard error of the mean (SE or  $s_x = s/n^{1/2}$ ) is determined then a corresponding weighted average for the season is determined. With  $n$  set to the maximum number of sensors for each crop (6 for soybean and 8 for maize), the corresponding variance is the best simple way to estimate the population variance ( $\sigma^2$ ) and resulting standard deviation ( $\delta$ ). The effect of the number of sensors is estimated from varying  $n$  in  $\sigma_x = \delta/n^{1/2}$  for each crop and sampling date.

Crop growth analysis methods and ideas were primarily from Hunt (1982). Parameterizations from Meek et al. (1991) were employed using nonlinear iteratively reweighted least-squares estimation (PROC NLIN in SAS v. 9.2.2). Three or more models were considered for each crop. In the models  $Y$  is the dry matter yield (g m<sup>-2</sup>) and  $x$  is DOY. Relative growth rate (RGR) is also estimated, where  $RGR = (1/Y)dY/dx$ . For the soybean model, a logistic equation was selected:

$$Y = \frac{796.4}{1 + e^{-0.07806(x-206.7)}}$$

Here  $R^2 = 0.975$  and diagnostics were reasonable. For the maize model, the Hill equation was selected:

$$Y = \frac{2289x^{15.17}}{e^{80.22} + x^{15.17}}$$

Here  $R^2 = 0.993$  and diagnostics were reasonable. The Hill model is a form of the logistic model with  $x$  replaced by  $\ln(x)$ .

Next a concept from measurement error regression is employed (see e.g., Fuller, 1987). Let  $X_t$  = CI-PAR, the observed sensor mean at any sampling date  $t$ . In ordinary regression analysis, the independent variable is assumed to be fixed without a random error. Here, obviously  $X_t = x_t + u_t$  where  $x_t$  is the true unobserved value of CI-PAR and  $u_t$  is the associated random error with a mean of zero and a variance of  $\sigma_{uu}^2$  over all  $t$ . Let the corresponding variances for  $x_t$  and  $X_t$  be and (note  $\sigma_{xx}^2 = \sigma_{xx}^2 + \sigma_{uu}^2$ ) then the reliability ratio is defined as  $k = \sigma_{xx}^2 / \sigma_{xx}^2$ . The  $\sigma_0$  estimates for each  $n$  are then used as random error estimate for a related assessment of the reliability ratio ( $k$ ) for using seasonal CI-PAR series from each crop field in an RUE model. For each crop both  $k$  and  $\Delta k / \Delta n$  are estimated from  $n = 1$  to the maximum number of sensors used.

<sup>1</sup> Mention of trade names or commercial products is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture.

Download English Version:

<https://daneshyari.com/en/article/4510754>

Download Persian Version:

<https://daneshyari.com/article/4510754>

[Daneshyari.com](https://daneshyari.com)