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Short Communication
Performance of LAI-2200 Plant Canopy Analyzer on Leaf Area Index of Jatropha Nut Estimation

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Abstract
Background and Objective: Leaf Area Index (LAI) of crops can be determined by many different methodologies with direct or indirect measurements. The use of sensors to estimate LAI has the advantage of fast and easy measurements, however, it is necessary to test and calibrate in order to verify its reliability. The objective of this study was to test and calibrate the LAI-2200 plant canopy analyzer on the estimative of LAI of jatropha nut trees. **Methodology:** The study was conducted in the experimental area of Biosystem Engineering, Department of ESALQ/USP, in Piracicaba, Sao Paulo, Brazil. The test was performed with 9 jatropha nut plants, by comparing estimated LAI data with LAI-2200 equipment with real LAI by destructive sampling. **Results:** The isolate plant measurement overestimated around 30% of real LAI and the pattern measurements underestimated around 10%. **Conclusion:** Both models were considered adequate according to the statistical parameters results and they can be used to correct estimated LAI in order to present better result of LAI for jatropha nut.

Key words: Sensor calibration, gap fraction, canopy light interception

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Leaf Area Index (LAI) of crops is a component used in many studies in different research area. The LAI, also expressed as foliage density (or area) by the surface area available to the plant (m^2 m^{-2}), can be used to comprehend within and below canopy microclimate change, an indicative of water consumption by the plants, sunlight interception and crop yield prediction[1].

The LAI can be determined by many different methodologies with direct and indirect measurement and depending on the method, it can be more or less complex with advantage or disadvantage[2,3]. The direct measurement provides reliable data, but is timing consuming and may be impractical according to the amount of data required. Indirect methods that use sensors to estimate LAI of crop is becoming very common due the advantage of performing multiples measurements in short time and it can be applied by any crop. One sensor that is widely used is the LAI-2200 plant canopy analyzer[4], which has the advantage of estimating LAI of crop in an easy, fast and simplified way. LAI-2200 uses a fish-eye sensor that estimates LAI from the light interception at five zenith angles. It calculates LAI by the gap fraction from above and below canopy measurements. In the literature, it is possible to observe many studies that use LAI-2200 and the previous version (LAI-2000) in different crops[5], eucalypt[6], pines[7] and forest[8].

Even though LAI-2200 is considered the world standard instrument to measure LAI for crop that has short homogeneous canopy such as soybean and wheat, the use of LAI-2200 for crop with high gap fraction or high seedling spacing is questionable. Usually, when intends to determine LAI of a single tree or crops with high gaps fraction between plants or rows, the manufacturer of LAI-2200 recommends that reading must be adjusted and recalculate[4], presenting the methodology called "Isolate plant". Jatropha nut (*Jatropha curcas* L.) crop used in this study, is a small tree with main characteristic of high percentage of oil within the seed that is used to produce biodiesel[9-12]. Jatropha nut is usually cultivated with high seedling spacing (3 m or higher between plants), requiring high criteria when performing reading with LAI-2200. Comparing real LAI index with measured LAI by the sensor is necessary to determine the influence of gap fraction and it is possible to establish a model that reduces the reading errors. Behera *et al.*[13], evaluating the performance of LAI-2000 plant canopy analyzer measurement for jatropha nut, performed several reading using all the sensors field view caps (11°, 45°, 90°, 180°, 270° and 360°) at 15 and 30 cm intervals from the stem base. They found that 90° narrow azimuthal viewing presented the best results with RMSE of 0.262 and 0.29 at 30 and 15 cm, respectively. However, the methodology used in this study did not meet with manufacturer recommendation for the jatropha nut canopy type. Finally, the author performed only one above reading and according to the manufacturer, for each below canopy reading and one above canopy reading must be performed at the same azimuthal direction so, the sensor is able to compare the gap fraction for all four direction. Therefore, it is necessary to understand the sensor reliability, especially when performing readings that meets to the manufacturer suggestions. Testing and calibration using adequate methodology as well as creating a relationship between real and estimated LAI are essential to establish the real reliability of LAI-2200 on LAI estimation for jatropha nut plant.

The objective of this study was to test and calibrate the LAI-2200 plant canopy analyzer sensor on the estimative of leaf area index of jatropha nut using the manufacturer's methodology recommendation.

MATERIALS AND METHODS

Field experiment: The study was conducted on experimental of 'Luiz de Queiroz' College of Agriculture (ESALQ) of University of São Paulo (USP), in Piracicaba city, Brazil (22°41'58'' S and 47°38'42'' W and at approximately 530 m of altitude). The performance of LAI-2200 test was conducted in the same research area of japropha nut with evapotranspiration and crop coefficient under enter pivot, drip and rainfed water management. The experiment had 2 ha, divided in 1 ha for center pivot, 0.5 ha for drip and 0.5 ha for rainfed. Plants were cultivated with 3×4 m plant and row spacing, respectively. Real and estimated LAI readings were performed with 9 jatropha nut plants from February, 2013 to April, 2013 and from January, 2014 to March, 2014 ranging from 29 and 43 months old plants, using plants during vegetative and productive growing stage. All measurements were taken under overcasting sky condition, always until 9:00 AM or after 5:00 PM, avoiding direct sunlight that could compromise the adequate reading.

LAI-2200 test and calibration: To perform the readings by the LAI-2200 plant canopy analyzer, it is necessary to understand how the readings are taken and how to adapt for the jatropha nut plant canopy type. Initially, LAI-2200 takes reading and calculates LAI for a hypothetical short homogenous canopy of 1 m height and these readings are considered the pattern measurement. However, in order to adapt the reading for jatropha nut canopy characteristic, it is necessary to recalculate the data using the LAI-2200 software provided by the manufacturer. By adding the plant canopy shape information into the software, it recalculates the previous estimated LAI (pattern measurement) to the isolate plant measurement. The test was performed in both approaches, one that met the manufacturer recommendation by the isolate plant measurement methodology and other using the pattern measurement.

Figure 1 is presented the methodology of isolated plant measurement that was performed in each of the 9 plants chosen to determine estimated LAI with LAI-2200. It was utilized a 90° sensor field cap at 10 cm intervals from the stem base and at 10 cm of ground level. To avoid interference by the surrounded plants, the readings were taken crosswise to the crop row. It was taken four reading above and below plant canopy with the sensor aimed to the outside of the plant, forming a 90° angle between directions (Fig. 1).

After performing the four direction readings, the equipment provides the pattern measurement and, in order to transform the results from pattern measurements, it was necessary to recalculate the data using the plant the LAI-2200 software (FV2200 v2.1.1). In Fig. 2 is presented the example of how the plant canopy shape was determined, considering × (plant canopy radius) and z (plant height) axes length (Fig. 2a) and how to recalculate the data using LAI-2200 software (Fig. 2b). Adding this information will provide a new LAI that meet to the plant canopy shape.

Figure 3 is presented the field and laboratory sequence of estimated and real LAI determination for each plant, showing the plant that was chosen to perform the readings (Fig. 3a), the estimative of LAI by the sensor using the isolated plant method (Fig. 3b). In sequence, all the leaves was manually removed from the plant (Fig. 3c) to determine to real LAI by the destructive method using the CI-203 leaf area integrator (Fig. 3d)[14].

Statistical analysis: The statistical criteria to evaluate LAI-2200 performance on the estimative of LAI was based on the coefficient of determination (R^2) and the Person correlation coefficient (r). Also, it was used the Root Mean Square Error (RMSE), the Nash Sutcliffe Efficiency (NSE)[15], the Willmott index of agreement (d)[16] and the index of confidence (c) proposed by Camargo and Sentelhas[17] from the comparison between real LAI (LAI_R) and recomputed LAI (LAI_{E_R}) and LAI_R and pattern LAI (LAI_{E_P}).

RESULTS AND DISCUSSION

In Fig. 4 is presented the scatted analysis between LAI_R and LAI_{E_R} (Fig. 4a) and between LAI_R and LAI_{E_P} (Fig. 4b). Although the isolate plant measurement is the recommended methodology the pattern measurement was also used due to advantage of hot requiring to recalculate the data using the LAI-2200 software, saving time in comparison to isolate plant measurement.

During the estimated LAI measurements, plants height were between 1.8 and 2.6 m (2.25 m average) and maximum canopy diameter ranging from 0.8-2.7 m (2.0 m average).

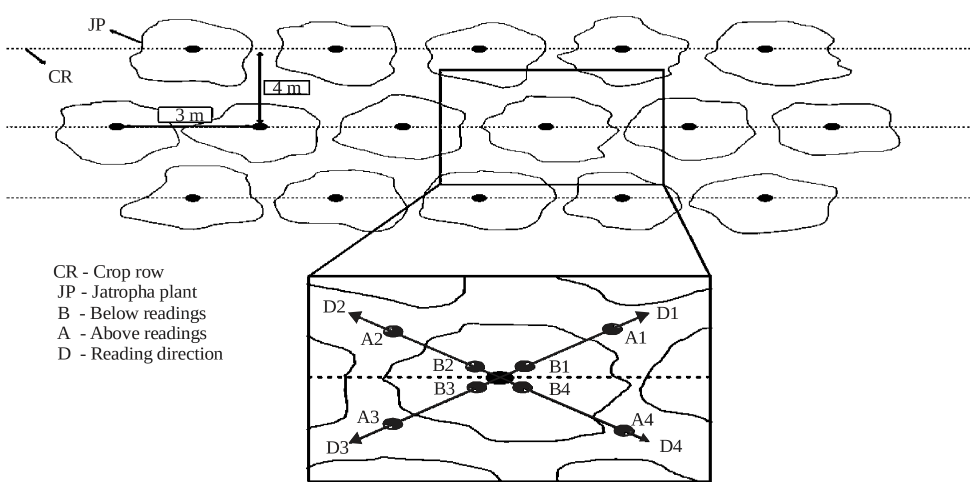

Fig. 1: Field layout of jatropha nut and the four crosswise row directions of above and below readings, of LAI-2200 plant canopy analyzer readings

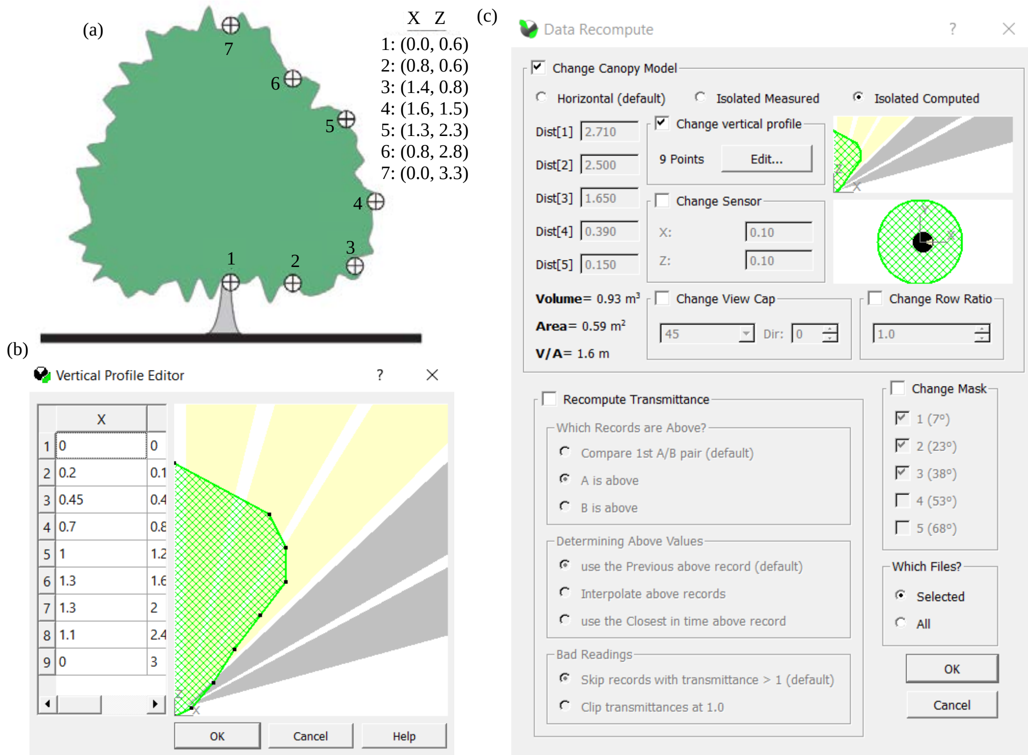

Fig. 2(a-c): (a) Plant canopy shape determination and (b and c) Data recalculate using FV2200 v2.1.1 Software

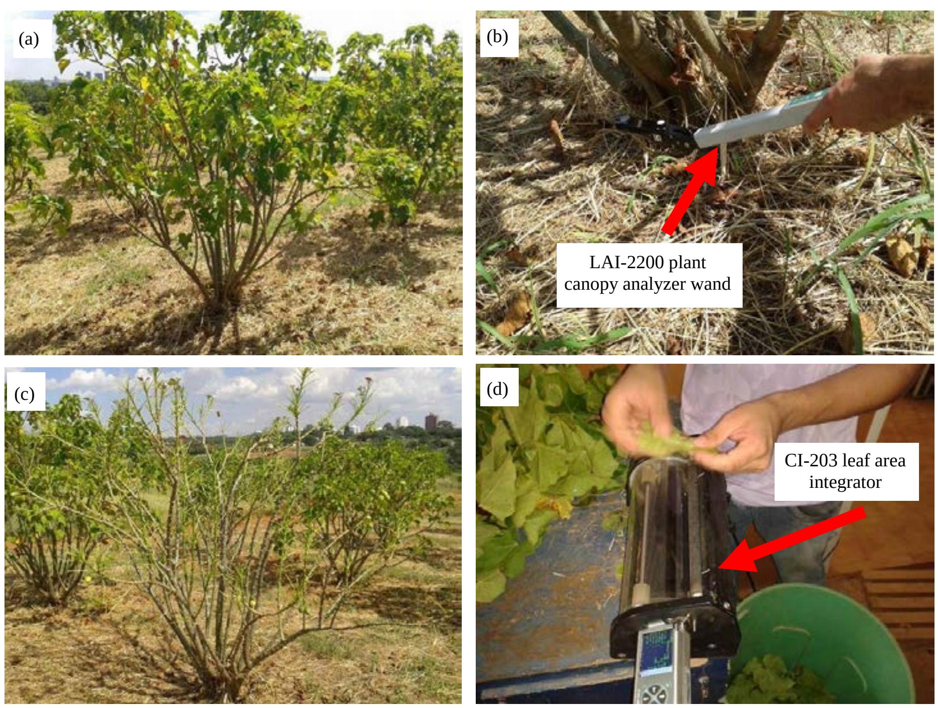

Fig. 3(a-d): Sequence of real and estimated LAI data measurement, (a) Plant chosen, (b) LAI-2200 reading, (c) Plant after leaves detachment and (d) Real leaf area index, use LAI determination by CI-203 leaf area integrator

Table 1: Coefficient of determination (R^2), correlation coefficient (r), Root Mean Square Error (RMSE), Nash Sutcliffe Efficiency (NSE), Willmott index of agreement (d) and Sentelhas-Camargo index of performance (c) values from the comparison between real LAI (LAI_R) and recomputed LAI (LAI_{E_R}) LAI_R and pattern LAI (LAI_{E_P})

Comparison	R^2	r	RMSE	NSE	d	c
LAI_R vs LAI_{E_R}	0.8832	0.9398	0.2534	0.2541	0.8878	0.8607
LAI_R vs LAI_{E_P}	0.8713	0.9335	0.1174	0.8400	0.9509	0.9187

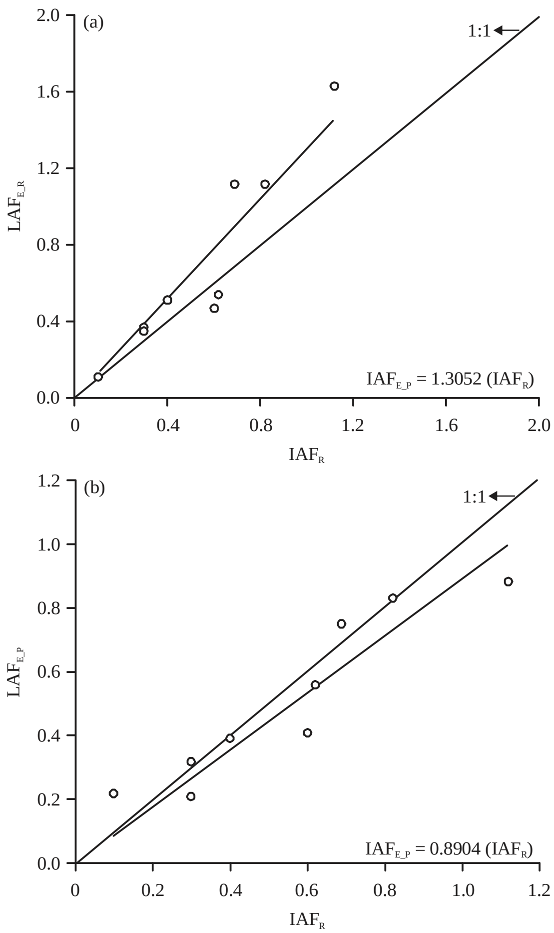

Fig. 4(a-b): (a) Comparison between real leaf area index (LAI_R) and isolated plant measurement estimated leaf area index (LAI_{E_R}) and (b) Pattern measurement estimated leaf area index (LAI_{E_P})

Estimated LAI ranged from 0.11-1.63 for LAI_{E_R} and from 0.22-0.88 for LAI_{E_P}, while LAI_R ranged from 0.10-1.12 with average values for LAI_{E_R}, LAI_{E_P} and LAI_R of 0.69, 0.51 and 0.55, respectively. Both comparison presented positive correlation between real and estimated LAI, with estimated LAI values by isolated plant measurement overestimated real LAI around 30% and the estimated LAI values by pattern measurement underestimated real LAI only in 10%. By the equations presented in Fig. 4, it is necessary to recalculate the LAI readings according to the proposed measurement methodology (Fig. 4a for isolate plant and Fig. 4b for pattern measurement). As result, the data will be transform to adequate values closer to real data.

Both approaches were statistically analyzed and the results are presented in Table 1. It was observed that, for both LAI_{E_R} and LAI_{E_P} models, they presented high R^2 and r, showing a very good correlation between estimated and real LAI, with low RMSE for both case. According to the d and c indexes values, they presented values considered "great" for both LAI_{E_R} and LAI_{E_P} models, but with a slightly higher values for LAI_{E_P} in comparison with LAI_{E_R}. The NSE value represents the model efficiency, also it is possible to affirm if the model may or may not represent real data. According to the values of NSE for LAI_{E_R} and LAI_{E_P} models, they were considered acceptable i.e., the model can be used to simulate real LAI in both measurement approaches. However, the LAI_{E_P} model had higher RMSE, NSE, d and c values in comparison with LAI_{E_R} model, showing that LAI_{E_P} model presented better accuracy, precision and smaller error. According to the analysis results presented in this study, for both measurement methodology approaches of LAI estimating for jatropha nut presented satisfactory performance in which is possible to affirm that estimating LAI by LAI-2200 provides reliable LAI data.

In the literature, it was found only one study that tested LAI-2000 (previous model of LAI-2200) on jatropha nut LAI estimation. This study was presented by Bahera *et al.*[13] and they found a linear regression for 90° field view cap with high R^2, showing that LAI-2000 had great estimative of LAI in jatropha nut plant. For others cultures, it is possible to find many studies that tested and calibrated LAI-2000 and LAI-2200, but usually the studies presented measurements methodologies that met each canopy structure for each study situation, differing from the methodology used in our study. Dovey and Toit[18], testing LAI-2000 estimates in young eucalypt forest with real LAI by destructive sample for 2 and 3 years old eucalypt plant, proposed two models (one for each year) that can be used to adequate LAI-2000 readings. Both models presented high R^2 (above 0.83), but for 2 and 3 years old the model underpredict and overpredict estimated LAI, respectively. Using many different indirect methods of determining LAI in medium size coffee trees (1.6 m height), Ribeiro *et al.*[19] observed that LAI-2000 presented a cubic model with low R^2 (0.3023). Although the authors used the same measurement methodology presented in this study (isolate plant measurement), they mention that using LAI-2000 for medium size coffee trees is a non-fitted instrument due it provides useful LAI estimation. The authors proposed using others indirect methods such as lux meter device, plant size approach and digital images in order to better estimate LAI for medium size coffee trees. With the objective of finding the best measurement approach of LAI-2000 estimation for soybean using the narrow-blue and wide-blue detectors, Malone *et al.*[20] observed that there was not statistically difference between estimated and real LAI for narrow-blue detector. In addition, as defoliaton plant level increased, the ability of the sensor to provide adequate estimated LAI decreased, showing that the sensor has not the ability of distinguish leaves from others parts of the plants such as pods, stems and petioles. In an experiment with two hybrid corn, LAI-2000, others two LAI equipment and was tested by Wilhelm *et al.*[21] using the short homogeneous canopy measurement. The authors found that for both hybrid LAI-2000 estimates provided positive correlation with a linear regression and R^2 higher than 0.75. Both models underestimated real LAI, so it is important to use the models to recalculate estimated LAI by LAI-2000.

The models proposed in this study using isolate plant and pattern measurement as well as those by Behera *et al.*[13]are considered essential to adequate the LAI reading on jatropha nut using LAI-2200. The user may choose which model is most suitable to his/her field situation, in which the reading will be performed according to the proposed model chosen. It is important to mention that the model meets the manufacturer recommendation is the isolated plant measurement and this model must be considered the most appropriate, when intents to determine LAI of jatropha nut.

CONCLUSION

The LAI-2200 plant canopy analyzer provided good estimated LAI data and comparing its estimates with real LAI was essential to find and correct errors. The results presented in this study showed that, while isolate plant measurement overestimated around 30% of real LAI, the pattern measurement underestimated around 10%. Both models were considered adequate according to the statistical parameters results and they can be used to correct estimated LAI in order to present better result of LAI for jatropha nut.

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