Article

Calibration of a prototype for continuous measurements of photosynthetically active radiation in sorghum

Gilbert Fresh López López[1]
Diego Cruz Hernandez[2]
Pedro Andrade Sanchez[3]
Santos Gabriel Campos Magaña[1]
Martin Cadena Zapata[1]
Juan Antonio López López[1§]

[1]Antonio Narro Autonomous Agrarian University-Department of Agricultural Machinery. Road Antonio Narro num. 1923, Buenavista, Saltillo, Coahuila, Mexico. CP. 25315. (gilbert.flopezl@uaaan.edu.mx; camposmsg@hotmail.com; martincadenaz@gmail.com; juan.alopezl@uaaan.edu.mx). [2]Postgraduate in Production Systems Engineering-Department of Agricultural Machinery-Antonio Narro Autonomous Agrarian University. Road Antonio Narro num. 1923, Buenavista, Saltillo, Coahuila, México. CP. 25315. (zynchd@hotmail.com). [3]University of Arizona-Department of Agricultural and Biosystems Engineering. Tucson, Arizona. (pcandradesanchez@gmail.com).

[§]Corresponding author: juan.alopezl@uaaan.edu.mx.

Abstract

This research aimed to calibrate the operation of a prototype for continuous measuring of photosynthetically active radiation (PAR) and validate it with field tests in sorghum cultivation (*Sorghum* spp.) at the final stage of its development. The prototype developed is based on two probes with 80 sensors (photodiodes). For calibration purposes, the output of this prototype was compared with a commercial sensor AccuPAR model LP-80 PAR/LAI Ceptometer (Decagon Enterprise), this calibration is explained by the slope of a linear regression model. The results obtained were a slope of 6.22963 μ mol $m^{-2}s^{-1}$ (mV x 10^2)$^{-1}$ with a coefficient of determination of 0.997, which met the statistical assumptions at 95%. In addition, the map of variability in the field is presented, whose values range from $\leq$ 794.4 to 2 160 μ mol m^{-2} s^{-1}, with the lower limit indicating that there is more foliage and the upper limit less foliage. From the data generated by the prototype, similarities to the commercial sensor were observed, suggesting that the prototype collects the data in less time and with greater sampling coverage, taking advantage of the window of opportunity of the diurnal solar radiation cycle.

Keywords: calibration equation, PAR prototype, precision agriculture.

Reception date: April 2021
Acceptance date: June 2021

Introduction

The photosynthesis rate of a plant is related to the amount of photosynthetically active radiation (PAR) that is absorbed by the plant (McCree, 1981). Under a plant canopy, radiation levels can range from full sun to almost zero over the space of a few centimeters. Therefore, for reliable PAR measurements, many samples in different locations under the canopy are required (Decagon, 2016).

PAR is a necessary input in commercial applications such as plant physiology, biomass production and natural lighting in a greenhouse. Unfortunately, PAR measurement is not an established common practice, it is currently calculated with a constant ratio of the broadband of solar radiation (Alados *et al*., 1996). Campbell (1981) mentioned that since it transfers radiation energy, it is important for plants for at least three reasons: 1) the photosynthetic rate of a plant is related to the amount of PAR absorbed by the plant; 2) the temperature of a plant is partly determined by the rate of absorption and emission of radiation; and 3) the photo morphological response of the plant is determined by the absorption of radiant energy in specific frequency band.

Appropriate specifications of environmental radiation properties included in each of these processes require knowledge of both radiant flux density and the distribution of the radiation frequency band, as spectral variation alters photosynthesis with the band length. The photosynthetic response per absorbed photon will not be independent of the spectrum of the light source (Erol and Akdeniz, 1996; Grignetti *et al*, 1997; Pax-Lenney and Woodcock, 1997; Haboudane *et al*., 2002).

Photon flux density in the frequency band 400 to 700 nm can be considered an adequate measure of PAR radiation, defined by studies of Gasstra (1959); Ross (1975), the execution of PAR measurements involves additional errors, which can be expected and compared in magnitude. Thus, in PAR measurement it is unlikely to exceed an overall accuracy of ±10%. Even this level of accuracy cannot be achieved without a good care in the design, calibration and use of instruments (Decagon, 2016; Zhou *et al*., 2016).

It should be noted that PAR is a measurement of the radiation available for photosynthesis and should not be treated as a universal measurement of the radiation available for growth. Unfortunately, there is no such measure. Radiation affects different growth processes, each of which must be treated independently (McCree, 1973; Shibles, 1976; Dybing, 1977). Viña and Gitelson (2005) mention that the quantification of the biophysical properties of terrestrial vegetation and their variation over time are important for a fast and accurate assessment of the state vegetation and its responses to changing environmental conditions.

One of these biophysical characteristics is the fraction of PAR absorbed. Data and techniques of remote sensors have already proved to be relevant to many crop inventory and monitoring requirements. Different studies and experiments demonstrated their usefulness and feasibility in addressing various agricultural issues, such as crop classification and their mapping. The purpose of this research is to generate the first calibration equation for a photosynthetically active radiation (PAR) measurement prototype in real time adjusted to a prediction model.

Materials and methods

The development of this research project was carried out at the facilities of Maricopa Agricultural Center experimental station of the University of Arizona in Maricopa, AZ, USA, in the winter period of 2016 and consisted of the design and construction of a prototype for data collection of photosynthetically active radiation (PAR) in continuous movement in a sorghum cultivation.

The conceptual design of the prototype is presented in Figure1, it is made up of: 1) an aluminum structural profile for quick assembly; 2) bearing type swivel wheel to be able to maneuver ; 3) two LP-80 type probes, each one has 80 photodiodes connected in parallel obtaining 8 sections and a resistance of 420Ω to capture the signal; 4) a John Deere StarFire300 GPS that has the ease of a connection compatible with the acquisition system by means of the RS-232 serial connection; 5) a Micrologger CR3000 (Campbell Scientific Company, USA) data acquisition system; 6) two buttons to start and pause data acquisition; and 7) 12V battery for power.

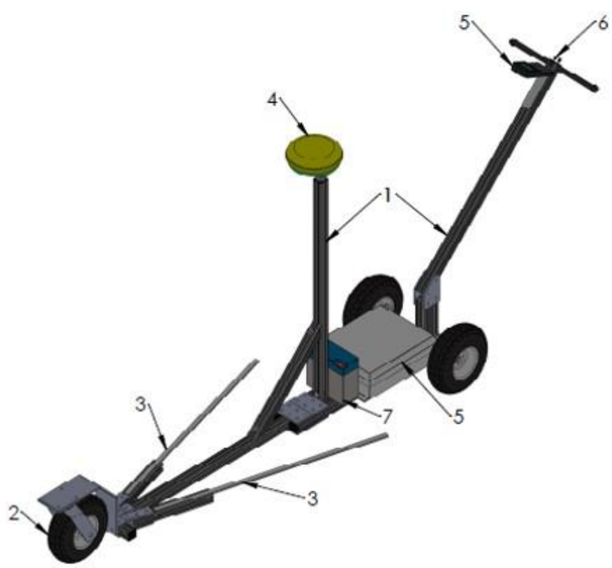

Figure 1. Conceptual design of the prototype.

First calibration equation

Data acquisition

In the F13 field located at 111°58’ 29.70’’ west longitude, 33° 4’ 31.40’’ north latitude at an altitude of 360 m. For the data acquisition of prototype, a control program was coded in the CRBasic Editor software, which had 16 sections alternately for the analog signal (voltage) of the sensors, GPS location. Buttons for start-pause and speed of the data acquisition at 5 Hz.

The control program was recorded on the CPU of the acquisition system. The data of the sensors were continuously recorded in a twelve-hour time range. On the other hand, the AccuPAR manual sensor model LP-80 PAR/LAI Ceptometer was used for manual measurement, taking average values of ten readings per hour throughout the prototype measurement (Figure 2).

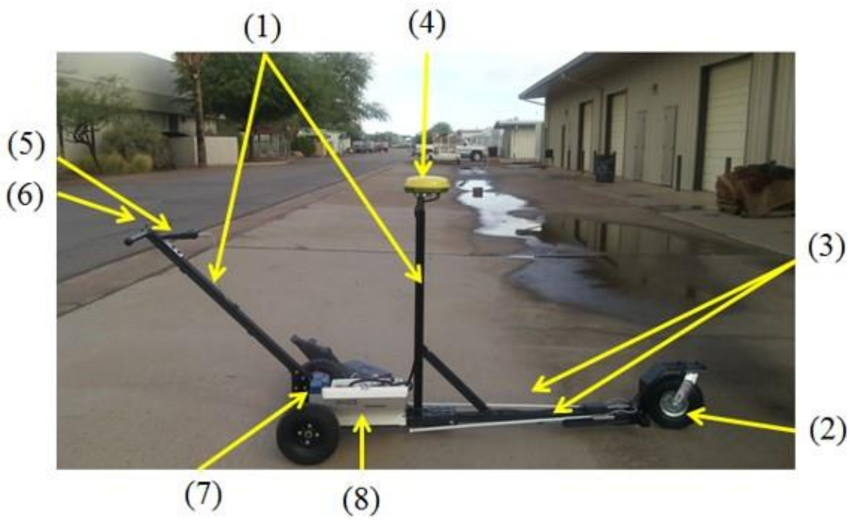

Figure 2. Elements that make up the prototype. 1) prototype chassis; 2) controller wheel; 3) sensors; 4) GPS; 5) control extension; 6) on-pause buttons; 7) 12V battery; and 8) CR3000 micrologger.

Calibration equation

$y_i = \beta_0 + \beta_1 x_i + \varepsilon_i$ To generate the calibration equation, the data of the prototype and sensor AcuPAR Ceptometer model LP-80 (manual) are adjusted. For analysis in software R v. 3.3.3 with a linear regression model (equation 1). The voltage averages of each hour of the eight sensor sections were added up to be compared with the average of every hour of the manual sensor and compare the statistical assumptions for the reliability of this, these tests are: normality (Shapiro-Wilk), independence of errors (Durbin-Watson and Box-Ljung) and heteroscedasticity (Breusch-Pagan). Where: y_i= independent variable (volts); x_i= photosynthetically active radiation (μ mol m^{-2} s^{-1}), β_0 y β_1= intercept and slope, respectively, ε_i= experimental error.

Field tests

For the validation of the first approximation of calibration, tests were carried out within the sorghum cultivation at its final stage of development, established in the F13 field. Static trials were performed on sites to compare the behavior. For the dynamic trials, routes were made from north to south in the window of opportunity, considering the best angle of the sun position with respect to the crop. And with this generate characterization maps of the PAR variable with the prototype.

Results and discussion

Figure 2 presents the prototype assembled with the components according to the conceptual design developed. For the prototype sensors, two graphs measured in voltages are presented in Figure 3, which describe the behavior of the readings in volts for the calibration for 12 hours, there is also an error due to the position of the sun when it rises and disappears shading the sensors.

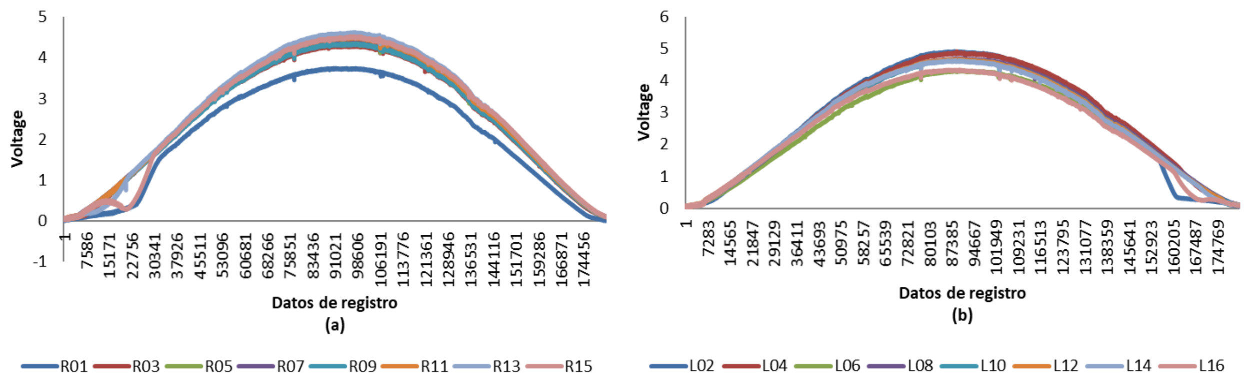

Figure 3. Readings of the prototype sensors on the a) right side; and b) left side.

Figure 4 shows the data of the manual sensor taken every hour; the sensor units are given in micromole per square meter per second (μ mol m^{-2} s^{-1}).

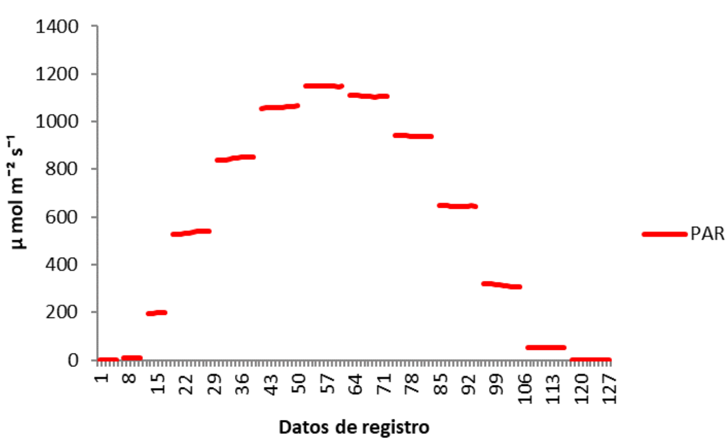

Figure 4. Data with the AccuPAR LP80 manual sensor.

Calibration equation

The calibration equation obtained was 6.22963 μ mol $m^{-2}s^{-1}$ $(mV^{-1} \times 10^{2})^{-1}$, described by the slope of the linear regression model, the dispersion and trend of the data are shown in Figure 5.

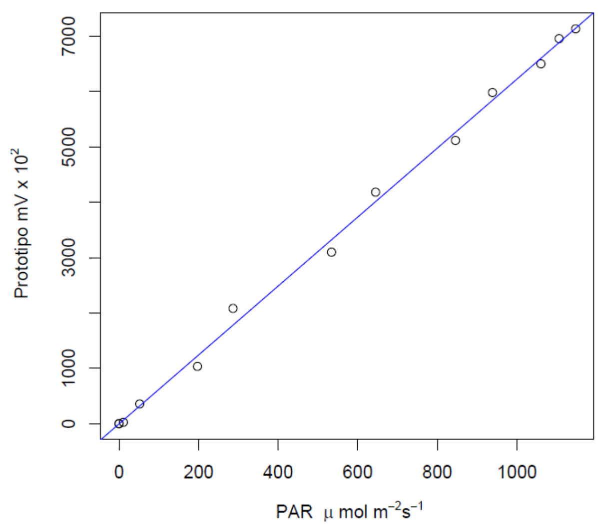

Figure 5. Scatter plot and trend of the data.

While the analysis in Table 1 shows that the slope is highly significant and the coefficient of determination (R^2) is 0.9973, this represents a high reliability of the model and therefore, a high reliability of the equation.

Table 1. Analysis of the linear regression model.

Coefficients	Estimate	Standard error	t value	Pr (>|t|)
Intercepto	-2.61578	67.09530	-0.039	0.97
RR	6.22963	0.09806	63.526	1.82e-15***
Residual standard error: 155.2 on 11 degrees of freedom				
Multiple R-square: 0.9973, adjusted R- square: 0.997				
F-statistic: 4036 on 1 and 11 DF, *p*-value: 1 822e-15				

Significance code= ***for $p \leq 0.001$.

The model meets the statistical assumptions at 95%, which indicates that the residuals have a normal distribution, there is residual independence and independent variances, this indicates that the method of analysis is reliable without suffer any bias.

Field tests

Figure 6 shows the tests for the static form comparing the LP80 manual sensor (blue line) with the voltage obtained by the prototype and multiplied by the calibration equation, called ‘estimated PAR’ (red line), the trend of the two apparatuses is similar, obtaining an average error of 5%.

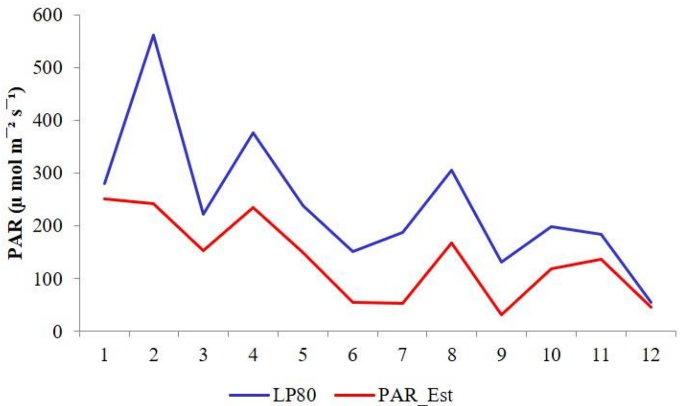

Figure 6. Chart of PAR field static tests.

In the static tests the characterization map of PAR is observe having higher field coverage in less sampling time and this makes it more efficient due to the sun's window of opportunity. Next, the map of the dynamic test is presented, where the site variability is observed. Figure 7 shows the map with a color scale, where the lighter color represents the lower PAR record, this indicates that in that area the foliage of the plant had greater coverage, and the area of intense color indicates that there was a greater record, meaning that the plants had less foliage.

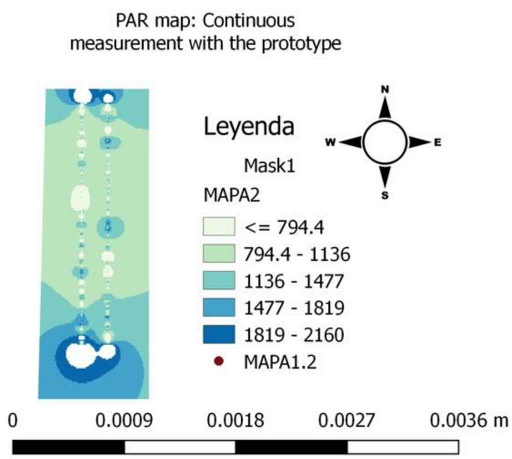

Figure 7. PAR characterization map.

Photosynthetically active radiation is found between 400 to 700 nanometers of the bandwidth. This represents the portion of the solar spectrum that plants use for photosynthesis. Under a plant canopy, radiation levels can range from high to low levels over the space of a few centimeters. Therefore, for higher reliability of the PAR measurement, many samples in different locations under the canopy and field sites are required (Decagon, 2016).

Andrade *et al*. (2004) mention that interest in the use of sensors for obtaining information of soil variables and crops has increased, many of these sensors are integrated with a GPS to obtain the maps of the different variables, because with higher data density better calculations can be made for decision-making. The coefficient of determination of the prototype obtained during the calibration shows high reliability for field use and to obtain more information on photosynthetically active radiation in less time.

Conclusions

The first calibration equation for the photosynthetically active radiation (PAR) measurement prototype was obtained, with a coefficient of determination of 0.9973 which represents sampling reliability and an average error of 5% compared to the AccuPAR LP-80 manual sensor.

Cited literature

Andrade, S. P.; Upadhyaya, S. K.; Jenkins, B. M.; Plouffe, C. and Poutre, B. 2004. Field evaluation of the improved version of the UCDavis compaction profile sensor (UCD CPS). Paper number 041037. ASAE Annual. Meeting. Doi:10.13031/2013.17644.

Alados, I.; Foyo-Moreno, I. and Alados-Arboledas, L. 1996. Photosynthetically active radiation: measurements and modelling. Agricultural and forest meteorology. 78(1996):121-131. Doi: 0168-1923(95)02245-7.

Decagon-Device, I. 2016. Accupar PAR/LAI Ceptometer model LP-80, operation's manual. http://library.metergroup.com/Manuals/10242_Accupar%20LP80_Web.pdf. 1-82 p.

Dybing, C. D. and Lay, C. 1981. Yields and yield components of flax, soybean, wheat, and oats treated with morphactins and other growth regulators for senescence delay 1. Crop Science. 21(6):904-908. https://doi.org/10.2135/cropsci1981.0011183X002100060025x.

Erol, H. and Akdeniz, F. 1996. A multispectral classification algorithm for classifying parcels in an agricultural region. Inter. J. Remote Sensing. 17(17):3357-3371. Doi: 01431169608949156.

Gaastra, P. 1959. Photosynthesis of crop plants as influenced by light, carbon dioxide, temperature and stomatal diffusion resistance. Meded Landbouwhogesch Wageningen. 59(13):1-68.

Haboudane, D.; Miller, J. R.; Tremblay, N.; Zarco-Tejada, P. J. and Dextraze, L. 2002. Integrated narrow-band vegetation indices for prediction of crop chlorophyll content for application to precision agriculture. Remote Sensing Environ. 81(2):416-426. Doi: 10.1016/S0034-4257(02)00018-4.

Mc-Cree, K. J. 1973. A rational approach to light measurement in plant ecology. Curr. Adv. plant sci. 3(4):39-43.

Mc-Cree, J. K. 1981. Photosynthetically active radiation. Physiological plant ecology I. Springer-verlag, Berlin. 12(01):41-55.

Pax-Lenney, M. y Woodcock, C. E. 1997. The effect of spatial resolution on the ability to monitor the status of agricultural lands. Remote Sensing Environ. 61(2):210-220. Doi: 10.1016/S0034-4257(97)00003-5.

Ross, J. 1975. Radiative transfer in plant communities. Monteith, J. (Ed.). vegetation and the atmosphere. Vol 1. Academic press. New York. 13-55 pp.

Shibles, R. 1976. Terminology relating to photosynthesis. Crop Sci. 16(3):437-439.

Viña, A. and Gitelson, A. A. 2005. New developments in the remote estimation of the fraction of absorbed photosynthetically active radiation in crops. Geophysical Research Letters. 32(17):1-4. Doi: 10.1029/2005GL023647.

Zhou, J.; Khot, L. R.; Bahlol, H. Y.; Boydston, R. and Miklas, P. N. 2016. Evaluation of ground, proximal and aerial remote sensing technologies for crop stress monitoring. IFAC-PapersOnLine. 49(16):22-26. Doi: 10.1016/j.ifacol.2016.10.005.