INNSPUB

Journal of Biodiversity and Environmental Sciences (JBES)
ISSN: 2220-6663 (Print) 2222-3045 (Online)
Vol. 5, No. 4, p. 371-377, 2014
http://www.innspub.net

RESEARCH PAPER | OPEN ACCESS

Estimating photosynthetically active radiation (PAR) using air temperature and sunshine durations

Abolfazl Majnooni-Heris

Department of Water Engineering, Faculty of Agriculture, University of Tabriz, Tabriz, Iran

Article published on October 21, 2014

Key words: Photosynthetically active radiation (PAR), Global solar radiation, sunshine hours, model.

Abstract

Photosynthetically active radiation (PAR) is a necessary input in applications dealing with plant top and underground dry matter production, plant physiology and natural lighting in greenhouses. Unfortunately, a worldwide routine network for the measurement of PAR is not yet established and it is often calculated as a constant ratio of the earth received solar radiation (Rs). Generation of simple models for independently and accurately estimating PAR from global solar radiation or other meteorological data is an important solution to the mentioned problem. In this paper, the ratio of PAR to Rs and their relations were analyzed. Then three global solar radiation estimation models were improved and calibrated based on the measured daily temperature and sunshine duration data for estimating PAR and PAR/Rs in an intermountain region of southern Iran. The average, maximum and minimum values of PAR to Rs ratio were 0.5857, 0.8841 and 0.4224, respectively during study years. Modification and calibration of Angstrom model for estimation of PAR values showed that the value of "a" and "b" coefficients are 0.188 and 0.338, respectively. In addition, the value of Hargreaves model coefficient calibrated as 0.0998 . The values of daily PAR were predicted based on global solar radiation by a simple linear equation. This simple equation constant was determined 0.584 that is very close to summation of Angstrom model coefficients, 0.526, in clear sky condition. The values of MBE, RMSE and NSE confirmed that three investigated models were appropriate for predicting photosynthetically active radiation.

***Corresponding Author:** Abolfazl Majnooni-Heris ✉ majnooni1979@yahoo.com

Introduction

Solar radiation provides light, heat and energy for all living organisms. Available solar energy for photosynthesis is known as photosynthetically active radiation (PAR), which is the spectral range of solar light from 400 to 700 nm that regulates primary productivity, or the rate of carbon fixed by aquatic and terrestrial plants. Incident PAR is required to model photosynthesis of single plant leaves or complex plant communities.

The fraction of absorbed photosynthetically active radiation absorbed by plant canopies is a critical biophysical variable for extrapolating ecophysiological measurements from leaf to landscape scale (Ogutu and Dash 2013). The absorbed PAR represents the available light energy for crop productivity and is therefore the essential variable influencing photosynthesis, transpiration and energy balance in most production efficiency models (Morisette *et al.* 2006, Gobron *et al.* 2006). In situ measuring the fraction of absorbed photosynthetically active radiation requires simultaneous measurement of photosynthetically active radiation (PAR) above and below a plant canopy (Gobron and Verstraete 2009).

In addition, photosynthetically active radiation is a main input in applications dealing with biomass production, natural illumination in greenhouses and plant physiology. Its estimation is important for many other applications such as ecological modeling.

Unfortunately, a worldwide routine network for the measurement of photosynthetically active radiation is not yet established and it is often calculated as a constant ratio of the broadband solar radiation (Alados *et al.* 1996).

Green vegetation can absorb up to 95 percentage of the incident PAR, the bulk of which is converted into latent and sensible heat. Only 5 percentage of PAR is consumed in photochemical processes in which CO_2 is assimilated as organic carbon (Myneni and Ganapol 1992).

Because of PAR importance in crop simulation models and it, vast application in simulation of plant top dry matter, absorbed photosynthetically active radiation fraction and soil surface evaporation, Frouin and Pinker (1995) used satellite observations to estimate photosynthetically active radiation. They reported satellite techniques are useful for modeling oceanic and terrestrial primary productivity. Fewer models are provided for estimating photosynthetically active radiation. In contrast, many models have been proposed for estimation of global solar radiation. Many presented solar radiation equations based on meteorological data have been discussed for determination of global solar radiation (Majnooni-Heris 2014, Almorox and Hontorio 2004) among which the most widely used is the Angstrom model (Angstrom 1924) that is based on sunshine duration. *Hargreaves and* Samani (1982) and Castellvi (2001) reported simple methods to estimate global solar radiation, which were a function of air temperature. Chen *et al.* (2006) and Majnooni-Heris (2014) developed several empirical global solar radiation models using meteorological variables in china and Iran, respectively. From the comparison of reported results, models based on sunshine hours could give more accurate results than the models based on other meteorological variables without sunshine hours (Majnooni-Heris and Bahadori 2014, Majnooni-Heris 2014, Zand-Parsa *et al.* 2011, Chen *et al.* 2006).

The main objective of this research is development and calibration of several photosynthetically active radiation (PAR) models using sunshine hours and air temperature data in an intermountain region of southern Iran.

Materials and methods

Study area and data collection

The experimental data were obtained from the weather station of Agricultural Research Station at Shiraz University in south of Iran. The latitude, longitude and elevation above mean sea level of the station are 29° 44´N, 52° 34´E and 1810 m, respectively. Daily data of photosynthetically active, global solar radiation (Rs) and sunshine hours (n) were measured from 2003 to 2005. Solar radiation was measured by solarimeter (507-250 pyranometer sensor, ELE, England) and sunshine hours were measured by Campbell–Stokes sunshine recorder (Lambrecht, Germany). The errors of the pyranometer for measuring solar radiation and sunshine recorder for measuring sunshine hours were found to be 5% and 10%, respectively.

Statistical analyses and methods of comparison

Measured data of global solar radiation and sunshine hours during 2003-2006 were used for modification of the Angstrom model. Models constants were estimated by minimizing the sum of square errors from measured and predicted values. Performance of the models were evaluated by statistical error tests including coefficient of determination (R^2), root mean square error (RMSE), mean bias error (MBE) and the Nash-Sutcliffe equation (NSE) (Nash and Sutcliffe 1970) as follows:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(P_i - O_i)^2}{n}} \quad (1)$$

$$MBE = \frac{1}{n}\sum_{i=1}^{n}(P_i - O_i) \quad (2)$$

$$NSE = 1 - \frac{\sum_{i=1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}(O_i - \bar{O})^2} \quad (3)$$

where n is the total number of measurements, i is the measurement number, O and P are the measured and estimated values, respectively and $\bar{O}$ is the average of measured values. A model is more efficient when *NSE* is closer to one. The mean bias error value provides information on the long-term performance. A low MBE is desired. A positive value gives the average amount of over-estimation of an individual measurement, which will cancel an under-estimation in separate measurements. The RMSE gives information on the short-term performance of the correlations by allowing a term-by-term comparison of the actual deviation between the predicted and measured data. The smaller the value, the better is the model's performance. However, a few large errors in the sum can produce a significant increase in the RMSE (Togrul and Togrul 2002, Menges *et al.* 2006).

Results and discussion

Photosynthetically active radiation estimation is important for many applications such as ecological modeling. Due to the cost, maintenance and calibration requirements of the measuring equipments in many developing countries, solar radiation measurements are not readily available. Therefore, it is important to elaborate models to estimate the global solar radiation based on the readily available data. In south of the Iran, there is low annual precipitation with high duration of sunshine and annual total global solar radiation. The mean measured annual sunshine hours, photosynthetically active radiation and global solar radiation were 3152 hr, 5026 MJ/m² and 8619 MJ/m², respectively during 2003-2005 at the studied station. For comparison, the mean values of measured sunshine hours and global solar radiation in Black Sea region were 1971 hr and 1120 kwh/m², respectively (Menges *et al.* 2006). Measured global solar radiation and photosynthetically active radiation during 2003-2005 are shown in fig. 1. In addition, variations of photosynthetically active radiation mean daily air temperature and actual sunshine hours are shown in fig. 2 during throughout the three-study years.

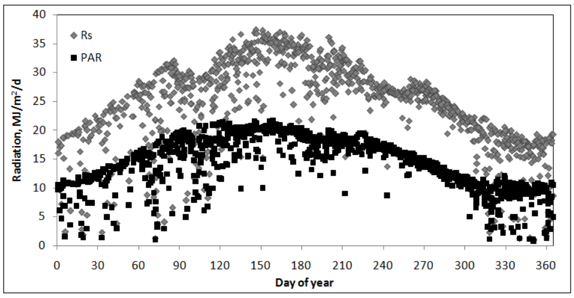

Fig. 1. Comparison between daily global solar radiation (Rs) and photosynthetically active radiation (PAR) during 2003 to 2005.

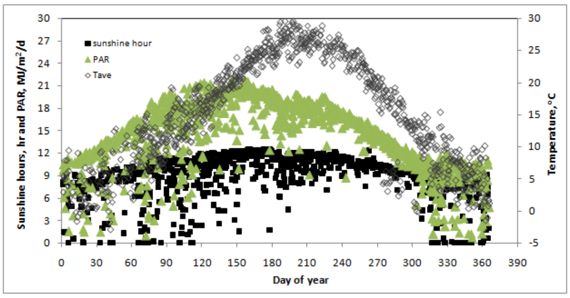

Fig. 2. Variations of photosynthetically active radiation mean daily air temperature and actual sunshine hours during study years.

The research area is located in the northern hemisphere and during fall and winter seasons, most of clouds come from the Mediterranean Sea. Therefore, according to fig. 2 the values of Rs and PAR during fall and winter seasons are less than spring and summer. Clear sky conditions were about 65 percent per year at the study area during 2003 to 2005.

The ratios of measured daily photosynthetically active radiation to global solar radiation are shown in fig. 3. The average, maximum and minimum values of PAR to Rs ratio were 0.5857, 0.8841 and 0.4224, respectively in the present research region.

Relationship between the ratios of measured daily photosynthetically active radiation to global solar radiation and ratio of actual solar radiation to maximum possible sunshine hour (n/N) is shown in fig. 4.

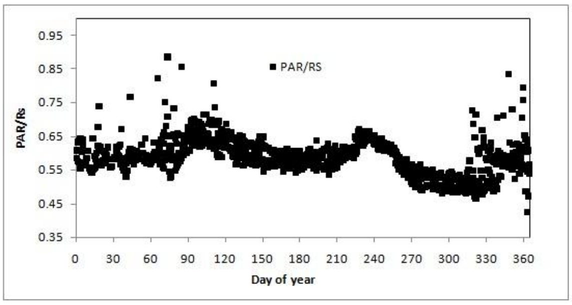

Fig. 3. The ratios of measured photosynthetically active radiation (PAR) to global solar radiation (Rs) during 2003-2005.

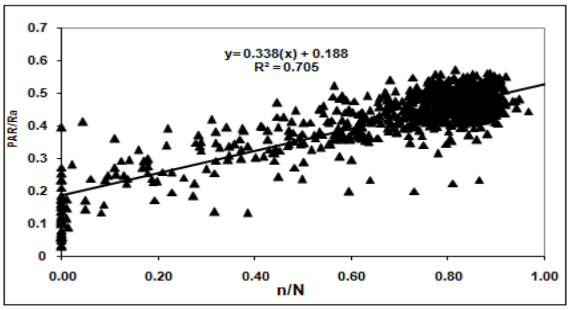

Fig. 4. Relationship between the ratio of measured photosynthetically active radiation to global solar radiation and ratio of actual sunshine hour to maximum possible sunshine hour (n/N) during 2003-2005.

Because of differences in sky-cloudiness, and atmosphere transmissivity in different days of year, the Angstrom model is modified for estimation of photosynthetically active radiation as follows:

$$PAR = Ra\left(0.188 + 0.338\frac{n}{N}\right) \qquad r = 0.84 \qquad (4)$$

where PAR and Ra are the photosynthetically active radiation and extraterrestrial radiation (MJ/m²/d), n and N are the measured and maximum possible duration of sunshine hours, respectively. Depending on the atmospheric conditions, humidity, dust and global solar declination the constants values including 0.188 and 0.338 are varied for different season and regions.

In above equation, the values of MBE, RMSE and NSE are 0 MJ/m²/d, 1.48 MJ/m²/d and 0.91, respectively. The value of MBE is close to 0.0 and the value of NSE is close to one. A model is more efficient when NSE is closer to one. The mean bias error value provides information on the long-term performance. A low MBE is desired in estimation of photosynthetically active radiation based on sunshine duration. Statistical result confirmed that the modified Angstrom model was more appropriate for predicting photosynthetically active radiation.

The relationship between measured PAR and Rs for study years are shown in fig. 5. The values of daily

PAR are predicted based on global solar radiation using the following equation during 2003 to 2005:

$$PAR = 0.584Rs \qquad r = 0.97 \qquad (5)$$

The values of MBE, RMSE and NSE are -0.02 MJ/m²/d, 1.1 MJ/m²/d and 0.95, respectively. Mentioned indices confirmed that above simple model was more appropriate for predicting photosynthetically active radiation and is recommended to be used in study region, where global solar radiation is calculated or measured only.

Investigation of equation 4 and equation 5 showed that the summation of equation 4 coefficients, i.e., 0.188+0.338=0.526, in clear sky condition (n=N) is very close to coefficient of equation 5 (i.e., 0.584).

The Hargreaves and Samani (1982) model is one of the most commonly used methods for estimation of global solar radiation based on maximum and minimum air temperature. In this research Hargreaves and Samani (1982) model was calibrated for prediction of photosynthetically active radiation as follows:

$$PAR = 0.0998\, Ra \sqrt{T_{max} - T_{min}} \qquad r = 0.89 \qquad (6)$$

The values of MBE, RMSE and NSE are 0 MJ/m²/d, 2.23 MJ/m²/d and 0.77, respectively. Mentioned statistical parameters indicated this simple model was appropriate for predicting photosynthetically active radiation and is recommended to be used in areas, where air temperature is measured only. Relationship between the measured and predicted values of photosynthetically active radiation by equation (6) are shown in fig. 6.

Mentioned presented models in this paper showed an overall good result. Therefore, these models are recommended to be used in study region for estimation of photosynthetically active radiation with higher accuracy.

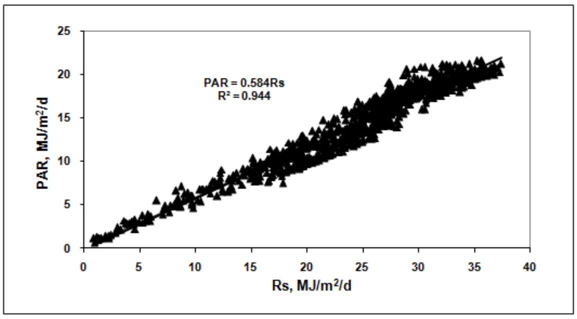

Fig. 5. The relationship between measured PAR and *Rs* during 2003-2005.

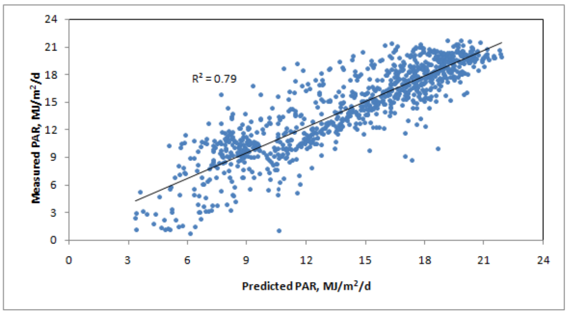

Fig. 6. Relationship between the measured and predicted values of photosynthetically active radiation by equation 6.

Conclusions

In south of Iran, there is low annual rainfall with high duration of sunshine, annual total global solar and photosynthetically active radiation. The mean measured annual sunshine hours, photosynthetically active radiation and global solar radiation were 3152 hr, 5026 MJ/m² and 8619 MJ/m², respectively during 2003-2005 at study station. Investigation of PAR to Rs ratios showed that these ratios were varied in present research area. The average, maximum and minimum values of PAR to Rs ratio were 0.5857, 0.8841 and 0.4224, respectively during study period. Modification and calibration of Angstrom model for estimation of PAR values showed that the value of "a" and "b" coefficients are 0.188 and 0.338, respectively. In this equation, the values of MBE, RMSE and NSE are 0 MJ/m²/d, 1.48 MJ/m²/d and 0.91, respectively. The value of MBE is close to 0.0 and the value of NSE is close to one. In addition, the value of Hargreaves model coefficient calibrated as 0.0998$C^{-0.5}$. The parameters of MBE, RMSE and NSE are 0 MJ/m²/d, 2.23 MJ/m²/d and 0.77, respectively. The values of daily PAR were predicted based on global solar radiation by a simple linear equation. This simple equation constant was determined 0.584 that is very close to summation of Angstrom model coefficients in clear sky condition. The statistical parameters confirmed that three investigated models were appropriate for predicting photosynthetically active radiation. Therefore, these models are recommended to be used in study region for estimation of photosynthetically active radiation with higher accuracy.

References

Alados I, Foyo-Moreno I, Alados-Arboledas L. 1996. Photosynthetically active radiation: measurements and modeling. Agricultural and Forest Meteorology **78**, 121–131.

Almorox J, Hontoria C. 2004. Global solar radiation estimation using sunshine duration in Spain. Energy Conversion and Management **45**, 1529–1535.

Angstrom A. 1924. Solar and terrestrial radiation. Quarterly Journal of the Royal Meteorological Society **50**, 121–5.

Castellvi F. 2001. A new simple method for estimating monthly and daily solar radiation. performance and comparison with other methods at Lleida (NE Spain); a semiarid climate. Theoretical and Applied Climatology **69**, 231–8.

Chen R, Kang E, Lu S, Xibin JY, Zhang Z, Zhang J. 2006. New methods to estimate global radiation based on meteorological data in China. Energy Conversion and Management **47**, 2991–2998.

Frouin R, Pinker R T. 1995. Estimating Photosynthetically Active Radiation (PAR) at the earth's surface from satellite observations. Remote Sensing of Environment **51**, 98-107.

Gobron N, Pinty B, Aussedat O, Chen JM, Cohen WB, Fensholt R, Gond V, Huemmrich KF, Lavergne T, Melin F. 2006. Evaluation of fraction of absorbed photosynthetically active radiation products for different canopy radiation transfer regimes: methodology and results using Joint Research Center products derived from Sea WiFS against ground-based estimations. Journal of Geophysical Research **111**, 13111–13115.

Gobron N, Verstraete MM. 2009. Assessment of the status of the development of the standards for the terrestrial essential climate variables: Leaf Area Index (LAI). Global Terrestrial Observing System Report. Rome, Italy No **66**.

Hargreaves GH, Samani ZA. 1982. Estimating potential evapotranspiration. J Irrig Drain Eng **108**, 225-230.

Majnooni-Heris A, Bahadori H. 2014. Calibration of the modified Angstrom global solar radiation models for different seasons in south of Iran. International Journal of Biosciences **3**, 53-60.

Majnooni-Heris A. 2014, Development of new models to estimate global solar radiation in northwest of Iran, Journal of Current Research in Science **3**, 390-394.

Menges HO, Ertekin C, Sonmete MH. 2006. Evaluation of global solar radiation models for Konya, Turkey. Energy Conversion and Management **47**, 3149–3173.

Morisette JT, Baret F, Privette JL, Myneni RB, Nickeson JE, Garrigues S, Shabanov NV, Weiss M, Fernandes RA, Leblanc SG. 2006. Validation of global moderate-resolution LAI products: a framework proposed within the CEOS land product validation subgroup. IEEE Transactions on Geosciences and Remote Sensing **44**, 214–231.

Myneni RB, Ganapol BD. 1992: Remote sensing of vegetation canopy photosynthetic and stomatal conductance efficiencies. Remote Sensing of Environment **42**, 217-238.

Nash JE, Sutcliffe JV. 1970. River flow forecasting through conceptual models. 1. A discussion of principles. Journal of Hydrology **10**, 282–290.

Ogutu BO, Dash J. 2013. An algorithm to derive the fraction of photosynthetically active radiation absorbed by photosynthetic elements of the canopy (FAPAR) from eddy covariance flux tower data. New Phytologist **197**, 511–523.

Togrul IT, Togrul H, Evin D. 2000. Estimation of monthly global solar radiation from sunshine duration measurements in Elazig. Renew Energy **19**, 587–95.

Zand-Parsa Sh, Majnooni-Heris A, Sepaskhah AR, Nazemosadat MJ. 2011. Modification of Angstrom model for estimation of global solar radiation in an intermountain region of southern Iran. Energy and Environment **22**, 911-924.