J. Bangladesh Agril. Univ. 3(2): 327–332, 2005 ISSN 1810-3030

# Simulation of solar radiation from temperature at Mymensingh, Bangladesh

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## Abstract

Solar radiation has a direct effect on plant growth and, thus, is required for many simulation models of crop growth and productivity, and evapotranspiration. For locations where measured values are not available along temporal and/or spatial scales, it can be estimated using empirical models. This study was conducted to simulate the solar irradiance from temperature using Richardson model. The effect of seasonality was investigated by subdividing the yearly data into two subsets, wet and dry period. The calibration coefficients are comparable with the values developed elsewhere. The calibrated models were then tested against independent data sets. For the yearly data, the root mean square error (RMSE) was 1.38 $MJ/m^2/d$ compared with 1.82 $MJ/m^2/d$ for wet period and 1.33 $MJ/m^2/d$ for dry period. The percentage error for yearly data was 17 , compared with 26.6 for wet period and 14.5 for dry period. Results showed that the simulation models provide reasonably accurate estimates of irradiance and hence, can be used for non-instrumented periods and at sites away from calibrated site. Seasonal subdivision of the data adds accuracy of estimates.

**Keywords:** Global radiation, Temperature, Photosynthesis, Bangladesh, Richardson model

## Introduction

Agriculture is an exploitation of thermal and radiative energy. Solar radiation affects many physiological processes, particularly photosynthesis. Global solar radiation is important for quantitative ecophysiological studies as the source of energy used in photosynthesis and evapotranspiration. These measurements are especially important for determining the irrigation water requirements and potential growth and yield of crops in agriculture. Historic estimates of daily global solar radiation are often required for climatic impact studies (Barr *et al.*, 1996). This is also needed for inputs in simulation models used in agricultural and ecological systems (Pickering *et al.*. 1994).

Despite the above importance there are few measurements of global radiation in Bangladesh (Talukder, 1987). The reason for this shortage of data undoubtedly lies in the comparative complexity and cost of the standard apparatus and the work necessary for the upkeep and calibration of the instruments. The currently available solar irradiation observations in Bangladesh are, however, too spare to meet the demand of relevant community. The station where the instrument is available, the data is not measured routinely because of fault of the instrument, which is not repaired within short time (due to lack of expert trouble-shooter and lengthy management process). Therefore, in most cases the data relating to specific locations and time scales, have to be modelled from alternative, existing other climatic data. Hossain (1985) derive a relationship between solar radiation and bright sunshine hour for Dhaka, Bangladesh, using the Angstrom's type equation. But the relation is location specific and can not be used for other location unless it is verified for that particular location. Another problem with this type of equation is that it requires bright sunshine hour data, which is not available outside the meteorological station. The alternative is to relate the solar radiation with easily measurable, temperature data.

The objective of this study is to develop a simulation model to predict solar radiation from commonly available, temperature data.

## Materials and Methods

**Site description and data collection:** The study site was Mymensingh ( $24^0 43'$ N, $90^0 26'$ E, and 19 m above Mean Sea Level (MSL)), Bangladesh. Solar radiation and other climatic data were collected from Bangladesh Meteorological Department.

### Simulation model

The simulation model tried was that of the form of Richardson (1985):

$$\frac{R_g}{R_a} = a(T_{max} - T_{min})^b \quad (1)$$

Where, $R_g$ = global radiation, $MJ.m^{-2}.d^{-1}$
$R_a$ = atmospheric or extra-terrestrial radiation, $MJ.m^{-2}.d^{-1}$
$T_{max}$ = maximum temperature of the day, $^0C$
$T_{min}$ = minimum temperature of the day, $^0C$
a, b = coefficient , that to be determined for the specific site

**Calculation of atmospheric (extraterrestrial) radiation:** The extraterrestrial radiation was calculated following the procedure of Smith *et al.* (1992):

$$R_a = \frac{24 \times 60}{\pi} G_{sc} . d_r (\omega_s \sin\psi \sin\delta + \cos\psi \cos\delta \sin \omega_s) \quad (2)$$

where, $R_a$ = extraterrestrial radiation ($MJm^{-2}d^{-1}$)
$G_{sc}$ =solar constant ($MJm^{-2}d^{-1}$) = 0.0820
$d_r$ = relative distance of earth and sun
$\psi$ = latitude (rad)
$\delta$ = solar declination
$\omega_s$ = sunset hour angle (rad)
and,

$$\omega_s = \arccos(-\tan\psi \tan\delta) \quad (3)$$

$$d_r = 1 + 0.033 \cos\left(\frac{2\pi}{365} J\right) \quad (4)$$

$$\delta = 0.409 \sin\left(\frac{2\pi}{365} J - 1.39\right) \quad (5)$$

J = number of the day in the year (Julian day)

### Seasonality in simulation

The weather of Bangladesh fall into two major seasons: wet (April – Sept.) and dry (Oct. – March) season. Wet season experiences major rainfall with high humidity, and the dry season experiences low rainfall and low humidity. The effect of seasonality was investigated by subdividing the yearly data into two subsets. The simulation were performed for wet and dry season separately, and also for combined data. The simulation presented here use daily data of 22 months.

### Validation of simulation model

Validation is essentially an independent test of the model, where the model predictions are compared with data not used in the calibration/development process (Donnigan, 1983). Evaluation of model performance should include both statistical criteria and graphical display.

Addiscott and Whitmore (1987) concluded that any one method of quantifying the discrepency between model output and observed data alone might be misleading, but several methods used together could summarize satisfactorily the closeness of a model's estimates and measurements. A model is a good representation of reality only if it can be used to predict an observable phenomenon with acceptable accuracy and precision (Loague and Green, 1991). The developed simulation model was tested with independent data sets (daily data of two months).

Additionally, the following statistics were used to indicate overall model performance:

(i) **Mean Bias** (Retta et al., 1996, Willmott, 1982):

$$\text{Bias} = \frac{1}{N}\sum_{i=1}^{N}(S_i - M_i) \quad \text{......... (6)}$$

(ii) **Mean Absolute Bias or error** (Fox, 1981):

$$\text{MAE} = \frac{1}{N}\sum_{i=1}^{i=N}|S_i - M_i| \quad \text{......... (7)}$$

(iii) **Root mean square error** (RMSE), which quantifies the dispersion between simulated and measured data (Gabrielle and Kengni, 1996; Quemada and Cabrera, 1995):

$$\text{RMSE} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(S_i - M_i)^2} \quad \text{......... (8)}$$

where $S_i$ and $M_i$ are the simulated and measured values for the $i$th observation and $N$ is the number of observations. Ideally, the value of RMSE should be zero.

iv) **Relative error (RE)** (Loague and Green, 1991):

$$\text{RE} = \frac{\text{RMSE}}{\bar{y}}.100 \quad \text{......... (9)}$$

where $\bar{y}$ is the mean of *observed* values.

v) **Index of Agreement (IA)** (Willmott, 1982, Lecina et al., 2003):

$$\text{IA} = 1 - \frac{\sum_{i=1}^{N}(O_i - S_i)^2}{\sum_{i=1}^{N}[O_i' + S_i']^2}, \qquad 0 \le \text{IA} \le 1 \quad \text{......... (10)}$$

where $O_i' = |O_i - \bar{S}|$, $S_i' = |S_i - \bar{S}|$, $O_i$ is the observed value, $S_i$ is the simulated value, $\bar{S}$ is the simulated mean,

## Results and Discussion

The fitted values of the model (form of equation 1) coefficients are summarized in Table 1. The effects of seasonality on the coefficient values are apparent.

**Table 1. Fitted values of model coefficients for different seasons and in combination**

| Season | Coefficients | |
|---|---|---|
| | *a* | *b* |
| Wet | 0.053 | 0.796 |
| Dry | 0.045 | 0.8157 |
| Combined | 0.0593 | 0.718 |

The simulation models can be written as:

(a). For wet season,

$$R_g = 0.053 R_a (T_{max} - T_{min})^{0.796} \quad \text{.......} \quad (11)$$

(b). For dry season,

$$R_g = 0.0454 R_a (T_{max} - T_{min})^{0.8157} \quad \text{.......} \quad (12)$$

(c). For whole year,

$$R_g = 0.0593 R_a (T_{max} - T_{min})^{0.718} \quad \text{.......} \quad (13)$$

The value of $R_a$ may be determined following the procedure outlined in materials and methods section.

Richardson (1985) found the values of coefficients '*a*' and '*b*' for the Oklama City, USA, as 0.0602 and 0.885, respectively. He reported a correlation coefficient of 0.67 for comparison of predicted and measured solar radiation for this technique. For Tifton, Gorgia (USA), Hook and McClendon (1992) derived coefficients '*a*' and '*b*' of 0.0846 and 0.680, respectively; and the correlation coefficient was 0.63.

Comparison between observed and model simulated outputs with independent data sets are shown in Figure 1. The simulated values are close to 1:1 line, indicating the closeness of observed data.

The statistical indicators of the performance of the models are summarized in Table 2.

**Table 2. Statistical indicators of simulation performance**

| Statistical indicator | Value under different seasons | | |
|---|---|---|---|
| | Wet season | Dry season | Combined |
| Correlation between observed and simulated value | 0.67 * | 0.78 * | 0.80 * |
| Mean Bias (MJ/m$^2$/d) | -0.45 | -0.82 | -0.85 |
| Mean absolute bias (MJ/m$^2$/d) | 1.55 | 1.18 | 1.4 |
| RMSE (MJ/m$^2$/d) | 1.82 | 1.33 | 1.38 |
| RE (%) | 26.6 | 14.5 | 17.1 |
| Index of agreement | 0.80 | 0.87 | 0.86 |

*Significant at level 0.001

For the yearly data, the root mean square error (RMSE) was 1.38 MJ/m$^2$/d, compared with 1.82 MJ/m$^2$/d for wet period and 1.33 MJ/m$^2$/d for dry period. The percentage error for yearly data was 17, compared with 26.6 for wet period and 14.5 for dry period. The index of agreement was highest for dry season (0.87) followed by combined data (0.86), and the wet season showed lowest index of agreement (0.80). Seasonal subdivision of the data adds accuracy of estimates.

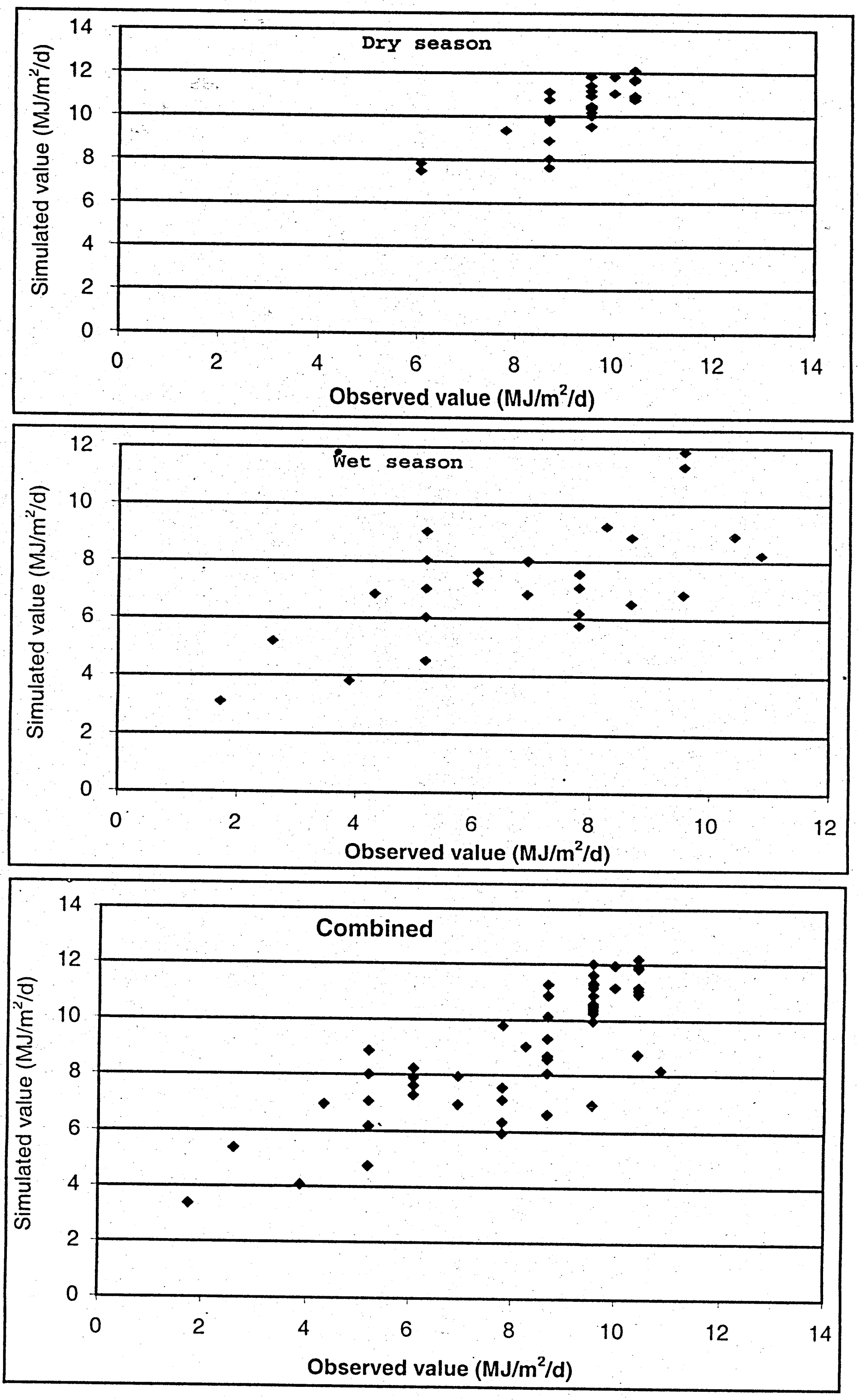


Fig.1. Comparison between observed and simulated values of solar radiation

The coefficients found in our analysis are in accord with the values found elsewhere. The statistical indicators of the model performance were also reasonable. Hence, the model can be regarded as reliable, and be used at sites where historical crop yield and other records are available for model validation, but solar radiation was not measured routinely. It can also be used for non-instrumented periods and at sites away from the calibrated site.

From the observation of simulated vs observed graph and from the statistical performance of the simulation models, it can be concluded that the simulation models can be used with confidence to estimate solar radiation from the temperature data.

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