



## Sensitivity analysis of performance of crop growth simulation models to daily solar radiation estimation methods in Iran

B. Farhadi Bansouleh<sup>a,b,\*</sup>, M.A. Sharifi<sup>a</sup>, H. Van Keulen<sup>c,d</sup>

<sup>a</sup> International Institute for Geo-Information Science and Earth Observation (ITC), P.O. Box 6, 7500 AA Enschede, The Netherlands

<sup>b</sup> Water Engineering Department, Faculty of Agriculture, Razi University, Kermanshah, Iran

<sup>c</sup> Plant Production Systems Group, Wageningen University, P.O. Box 430, 6700 AK Wageningen, The Netherlands

<sup>d</sup> Plant Research International, Wageningen University and Research Centre, P.O. Box 16, 6700 AA Wageningen, The Netherlands

### ARTICLE INFO

#### Article history:

Received 24 November 2008

Accepted 29 June 2009

Available online 30 July 2009

#### Keywords:

WOFOST

Ångström

Hargreaves

Barley

Maize

### ABSTRACT

Solar radiation is the single most important environmental factor driving canopy photosynthesis and transpiration. This weather characteristic is measured only in a limited number of weather stations. Hence, in many situations it has to be estimated from other weather characteristics such as sunshine duration and temperature using empirical relations. In this study, the Ångström and Hargreaves formulas have been used for solar radiation estimation, based on monthly and annual weather data for three weather stations in Esfahan province, Iran. Deviations of estimated solar radiation from measured values (both absolute and relative) varied with month of the year and with estimation method. Estimated and measured radiation values were used in a crop growth simulation model to explore sensitivity of simulated production with respect to radiation estimation method. Maximum deviation for winter barley and silage maize was around 9%.

© 2009 Elsevier Ltd. All rights reserved.

### 1. Introduction

Crop growth models are computer programs that integrate information on daily weather, crop characteristics, soil characteristics, and management to calculate crop growth and yield [1]. They are used, among others, to support agricultural decision-making and learning processes [2,3].

Solar radiation provides energy for photosynthesis and (evapo)transpiration of crops and soils [4–6]. Daily solar radiation is therefore one of the major inputs in crop growth models [7–9], required for calculation of daily gross CO<sub>2</sub> assimilation, the basis for dry matter production and yield.

In spite of the importance of solar radiation for crop growth, it is not routinely measured at all meteorological stations, probably because of the cost and the maintenance and calibration requirements of the measuring equipment [10–12]. A number of empirical relations of varying complexity have been developed to estimate solar radiation at a given location from other climatic characteristics that are measured more frequently [13]. Relations have been established with sunshine duration [14–16], air temper-

ature [17–19], cloud cover [6,20] and combinations of different weather characteristics [21,22]. Results of these studies have shown that sunshine-based models are more accurate than temperature-based models for estimation of daily solar radiation [13,23,24].

Crop growth models have been tested for sensitivity of simulated crop yields to inaccuracies in solar radiation estimates [12,25,26]. These analyses have included use of (10-day, monthly and seasonal) average weather data instead of daily data [27], using radiation from nearby stations [28], estimation of daily solar radiation from monthly means [29], exploration of climate change effects on solar radiation [30], and filling missing data of radiation by values generated by different methods of solar radiation estimation [4]. Fodor and Kovacs [26], using crop growth model 4M [31] to analyze the sensitivity of yield to inaccuracies in measurements of weather characteristics, found that 2% error in solar radiation caused 3.7% and 2.3% error in simulated grain yield and biomass of maize, respectively. They also showed significantly larger inaccuracies in calculated yield due to errors in measured radiation in years with low yields than in years with high yields. Nonhebel [12,25] showed deviations of 5–10% in the simulated yield of spring wheat in both, the water-limited and potential production situations [32] with 10% inaccuracy in solar radiation. Water-limited production appeared less sensitive to inaccuracies in solar radiation than potential production. The analysis also showed that randomly replacing 10% of

\* Corresponding author. Address: International Institute for Geo-Information Science and Earth Observation (ITC), P.O. Box 6, 7500 AA Enschede, The Netherlands. Tel.: +31 53 4874261; fax: +31 53 4874575.

E-mail addresses: [bfarhadi2001@yahoo.com](mailto:bfarhadi2001@yahoo.com), [farhadibansouleh@itc.nl](mailto:farhadibansouleh@itc.nl) (B. Farhadi Bansouleh).

the solar radiation data by average values did not significantly affect simulated water-limited and potential yields of spring wheat. Xie et al. [28], in analyzing the sensitivity of sorghum and maize yields to solar radiation found changes of less than 8% at 10% changes in solar radiation.

Trnka et al. [24] analyzed the effects of different estimation methods for daily global solar radiation on simulated yields of winter wheat and spring barley in the Czech Republic and Austria, using the WOFOST [9] and CERES [33,34] crop growth models. Simulated yields based on solar radiation estimated by the Ångström–Prescott [35] and Hargreaves [16] formulas deviated more than 10% from simulated yields based on measured radiation in 6% and 48% of the cases, respectively (in 1.4% and 16.3% of the cases deviations exceeded 25%). Moreover, the sensitivity varied with soil type. As a result of the model structure, diverging values of solar radiation resulted in many cases in disproportionate diversions in actual transpiration.

Soltani et al. [29] investigated the sensitivity of simulated yields of wheat, maize and soybean to daily radiation generated by linear interpolation from monthly means. Their results showed around 23% difference from yields simulated on the basis of measured radiation. They concluded that only in specific situations, monthly average radiation data can be used as input in crop growth simulation models.

Pohlert [4] randomly replaced 4.8% of the measured solar radiation data in two temperate (Wageningen, The Netherlands and Cordoba, Spain) and one tropical location (Los Baños, Philippines) by values estimated by different methods. Yields of maize, simulated with WOFOST [9] with these different sets of radiation data, were not significantly different. Nonhebel [27] found that use of average weather data in crop growth simulation models in the water-limited production situation resulted in overestimation of spring wheat yields in wet conditions and underestimation in dry conditions.

In most studies reviewed here, a fixed percentage of error (over- or under-estimate), uncertainty or change in solar radiation has been considered. Radiation estimates based on various methods produced different results with different magnitudes of error. Moreover, in most cases, sensitivity analyses of crop yields were based on empirical formulas with annual coefficients. However, it has been shown that these coefficients may show strong temporal variation [10]. Moreover, daily solar radiation estimated with empirical formulas may show much larger deviations from measured values than have been established in earlier work.

The objective of this study was to examine the sensitivity of potential yields and evapotranspiration of a winter crop and a summer crop grown in Iran, simulated by the WOFOST model [9] to radiation estimates by sunshine and temperature-based models with different sets of annual and monthly coefficients for three weather stations.

## 2. Material and methods

First, radiation is estimated by the Ångström and Hargreaves equations, as representative of sunshine-based and temperature-based models, respectively, with different sets of annual and monthly coefficients in three weather stations in Esfahan province, Iran. The estimated values are then compared with measured data from those stations. The WOFOST crop simulation model [9] is used for simulation of potential production and transpiration of winter barley (winter crop) and maize (summer crop). Sensitivity analysis on final yield and total potential transpiration of these crops is carried out with respect to different methods of solar radiation estimation. The process is graphically presented in Fig. 1.

### 2.1. Data and study area

Daily weather data of the synoptic weather stations of Esfahan (altitude 1550 meter above sea level), Najaf Abad (1641 m asl) and Kaboutar Abad (1545 m asl), established in 1951, 1987 and 2003, respectively, located in Esfahan province, Iran (Fig. 2), have been collected from the Iranian Meteorological Organization (IRIMO). The distance between Esfahan station and Najaf Abad and Kaboutar Abad stations is 27 and 22 km, respectively, and that between the stations of Kaboutar Abad and Najaf Abad 45 km. Kaboutar Abad is located close to a mountain and Esfahan close to a hill, but no major barriers exist between the weather stations (Fig. 2). Table 1 shows average monthly weather characteristics for Esfahan (1951–2003) and Kaboutar Abad (1987–2003) stations [36]. For Najaf Abad, recently established, no average data are available yet.

### 2.2. Calculation of solar radiation

Two approaches for estimation of solar radiation have been selected, the equation of Ångström–Prescott and that of Hargreaves.

#### 2.2.1. Ångström–Prescott

The Ångström–Prescott equation [35,37] has been widely used in solar radiation research:

$$\frac{R_s}{R_a} = a + b * \left(\frac{n}{N}\right) \quad (1)$$

where  $R_s$  is the total daily global radiation ( $\text{MJ m}^{-2}$ ),  $R_a$  the daily extra-terrestrial solar radiation ( $\text{MJ m}^{-2}$ ),  $n$  the actual sunshine duration (h),  $N$  the potential sunshine duration (h), and  $a$  and  $b$  are the regression coefficients. Coefficient  $a$  expresses the fraction extra-terrestrial radiation reaching the earth' surface on fully overcast days ( $n = 0$ );  $(a + b)$  the fraction reaching the earth' surface on clear days ( $n = N$ ). Extra-terrestrial solar radiation ( $R_a$ ) and potential sunshine duration ( $N$ ) can be calculated from geographical coordinates and Julian calendar date [38]. Global radiation and actual sunshine duration are measured in weather stations.

Values of the regression coefficients  $a$  and  $b$  vary in dependence of atmospheric conditions (humidity, dust content, type and thickness of cloud cover and concentration of pollutants) [10] and of solar declination (latitude and day of year) [38]. Moreover, the value of coefficient  $a$  has been reported to vary with altitude of the station [39]. Values of  $a$  and  $b$  should be derived therefore, by analyzing actual measurements of both total global radiation and sunshine duration.

Measured data of radiation and sunshine duration from the selected weather stations are used for estimation of Ångström coefficients, using linear regression between daily values of ( $R_s/R_a$ ) and ( $n/N$ ).

#### 2.2.2. Hargreaves

When only minimum and maximum temperatures are available, Hargreaves equation [16] can be used:

$$R_s = a * R_a * \sqrt{T_{\max} - T_{\min}} + b \quad (2)$$

where  $R_s$  is the daily total global radiation ( $\text{MJ m}^{-2}$ ),  $R_a$  the daily extra-terrestrial solar radiation ( $\text{MJ m}^{-2}$ ),  $T_{\max}$  and  $T_{\min}$  the daily maximum and minimum temperature ( $^{\circ}\text{C}$ ), and  $a$  and  $b$  are the regression coefficients.

Again, the regression coefficients vary with geographical location and should be derived by analyzing actual measurements of daily global radiation and minimum and maximum temperatures. Hargreaves coefficients for the selected weather stations are determined using linear regression between daily values of ( $R_s$ ) and ( $R_a * (T_{\max} - T_{\min})^{0.5}$ ).

متن کامل مقاله

دریافت فوری ←

**ISI**Articles

مرجع مقالات تخصصی ایران

- ✓ امکان دانلود نسخه تمام متن مقالات انگلیسی
- ✓ امکان دانلود نسخه ترجمه شده مقالات
- ✓ پذیرش سفارش ترجمه تخصصی
- ✓ امکان جستجو در آرشیو جامعی از صدها موضوع و هزاران مقاله
- ✓ امکان دانلود رایگان ۲ صفحه اول هر مقاله
- ✓ امکان پرداخت اینترنتی با کلیه کارت های عضو شتاب
- ✓ دانلود فوری مقاله پس از پرداخت آنلاین
- ✓ پشتیبانی کامل خرید با بهره مندی از سیستم هوشمند رهگیری سفارشات