Science of the Total Environment 511 (2015) 562–575

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Advancing the climate data driven crop-modeling studies in the dry areas of Northern Syria and Lebanon: An important first step for assessing impact of future climate

Prakash N. Dixit *, Roberto Telleria

International Centre for Agricultural Research in the Dry Areas (ICARDA), P.O. Box 950764, Amman 11195, Jordan

HIGHLIGHTS

- LARS-WG performed better than MarkSim in generating daily weather parameters.
- LARS-WG can serve as an important tool for long-term yield simulation and risk analysis.
- LARS-WG can be employed for generating site-specific climate change scenarios in Northern Syria and Lebanon.
- More than 10 years of observed weather data as input is sufficient for LARS-WG except in high altitude sites.

ARTICLE INFO

Article history:
Received 27 June 2014
Received in revised form 2 January 2015
Accepted 2 January 2015
Available online xxxx

Editor: E. Capri

Keywords:
Crop simulation
Climate data generation
Dry environment
Syria
Lebanon

ABSTRACT

Inter-annual and seasonal variability in climatic parameters, most importantly rainfall, have potential to cause climate-induced risk in long-term crop production. Short-term field studies do not capture the full nature of such risk and the extent to which modifications to crop, soil and water management recommendations may be made to mitigate the extent of such risk. Crop modeling studies driven by long-term daily weather data can predict the impact of climate-induced risk on crop growth and yield however, the availability of long-term daily weather data can present serious constraints to the use of crop models. To tackle this constraint, two weather generators namely, LARS-WG and MarkSim, were evaluated in order to assess their capabilities of reproducing frequency distributions, means, variances, dry spell and wet chains of observed daily precipitation, maximum and minimum temperature, and solar radiation for the eight locations across cropping areas of Northern Syria and Lebanon. Further, the application of generated long-term daily weather data, with both weather generators, in simulating barley growth and yield was also evaluated. We found that overall LARS-WG performed better than MarkSim in generating daily weather parameters and in 50 years continuous simulation of barley growth and yield. Our findings suggest that LARS-WG does not necessarily require long-term e.g., >30 years observed weather data for calibration as generated results proved to be satisfactory with >10 years of observed data except in area with higher altitude. Evaluating these weather generators and the ability of generated weather data to perform long-term simulation of crop growth and yield is an important first step to assess the impact of future climate on yields, and to identify promising technologies to make agricultural systems more resilient in the given region.

1. Introduction

Crop modeling studies are important to add value to field based agronomic experiments. These studies are climate data driven and serve as a primary tool in assessing the impacts of current climate (Dixit et al., 2011) and climate change (Webber et al., 2014) on crop productivity, which is a key aspect for ensuring food security (FAO et al., 2013). Factors such as time of sowing, plant population, fertilizer use, improved rainfall management through mulching or contrasting tillage techniques and their interaction with contrasting crop cultivars and improved crop genotypes have been extensively studied and reported. However, one factor that constrains such work is the length of time that such studies could be continued. Normally such studies hardly exceed four to five years and more recent evidence suggests that even shorter term studies are becoming the norm (Bationo et al., 2007). Given the variability in climatic parameters from year to year, large variations of seasonal rainfall, the impact that rainfall amounts and

* Corresponding author.
E-mail address: p.dixit@cgiar.org (P.N. Dixit).

http://dx.doi.org/10.1016/j.scitotenv.2015.01.001

distribution will have on the results obtained through field studies and the questionable ability of four to five seasons of research to capture the full extent of the longer-term climatic variability, it is important that alternative approaches to more detailed climate-induced risk analyses should be evaluated (Dixit et al., 2011). Without such detailed analyses, farmers can hardly be properly informed about the full nature of such risk and the extent to which modifications to crop, soil and water management recommendations may be made to mitigate the extent of such risk.

One of the most important ways to address this is through the use of crop growth simulation model. One of the advantages of the use of a crop growth simulation model is that specific treatments can be investigated in great detail without the corresponding costs associated with field work. When driven by long-term (>30 years) daily weather data, crop growth simulation model can be used to predict the impact of climate-induced risk on crop growth and yield. However, often the existence, availability, access to, or required cost of high quality, long-term daily weather data can present serious constraints to the use of crop models. In such instances, the use of stochastic weather generators can help overcome this constraint but there is a danger associated with the use of generated climatic data using weather generators without sufficient validation being carried out for the sites at which they are applied. Most weather generators have been tested intensively, but usually only for one country or one region (Semenov et al., 1998).

Apart from their use in providing long enough synthetic weather data in assessment of risk in agricultural applications, stochastic weather generators can be used to generate weather data in locations where observed information is not available at all by interpolating the parameters of a weather generator between sites where weather generator has been tested against observed data (Semenov et al., 1998). Another important application of stochastic weather generators is in climate change studies.

Recent researches (Ababaei et al., 2010; Castellvi et al., 2004; Hartkamp et al., 2003; Jones, and Thornton, 2000; Qian et al., 2005; Semenov et al., 1998; Soltani and Hoogenboom, 2003) have shown the use of weather generators in generating synthetic long-term daily weather data which matches the statistical properties of observed daily weather data at a given location. This generated data can be useful for crop growth and yield simulation for long-term (Hansen and Mavromatis, 2001; Mavromatis and Hansen, 2001). Hence, out of the previous discussion, two main problems emerge: 1) lack of long-term weather data to assess the long-term risk of crop production and 2) not enough validation of generated climatic data. In view of these problems and to advance the crop modeling studies in the region which heavily depends on good quality daily weather data for long-term, the objectives of this study are: i) to assess the quality of generated weather data and test their statistical performance compared to the observed weather data and ii) to evaluate the performance of generated long-term daily weather data in simulating yield and length of growing period of barley crop in Northern Syria and Lebanon.

Several weather generators have been developed for generating daily weather data. Some of these include LARS-WG (Semenov and Barrow, 1997; Semenov et al., 1998), WGEN (Richarsdon and Wright, 1984), SIMMETEO (Geng et al., 1986, 1988), MarkSim (Jones and Thornton, 2000) and others (e.g., Guenni et al., 1991; Hayhoe, 2000; Larsen and Pense, 1982) as reported by Wilks and Wilby (1999) and Soltani and Hoogenboom (2003). In this study, we used two weather generators LARS-WG and MarkSim that have been previously used for generating daily weather data (Hartkamp et al., 2003; Qian et al., 2005; Semenov et al., 1998; Soltani and Hoogenboom, 2003) and for use in crop simulation models (Hartkamp et al., 2003; Mavromatis and Hansen, 2001). While LARS-WG requires observed daily weather data as input to calibrate it for a site before generating the weather data, MarkSim requires only site parameters e.g., latitude, longitude and altitude. In order to explore the possibility of using the weather generator when some years of observed daily weather data is available for calibration and when no observed data is available at all, these two weather generators make sensible choice.

2. Materials and methods

2.1. Study sites and data

For this study, eight locations across Northern Syria and Lebanon were selected where ICARDA and local agricultural research institutes have maintained on-farm weather stations. Six locations were spread across the barley growing belt of Northern Syria, while two were located in the fertile Bekaa Valley in Lebanon. The selection was based on the availability of long-term daily weather data ranging from 11 to 33 years (Table S1, supporting documentation) from the barley growing areas. The data were obtained from the Geoinformatics unit of ICARDA, who managed the inventory of these data. The rainfall in these areas predominantly occurs from November to May, for about seven months, on which the cropping seasons lie. About 90% or more of the total annual rainfall takes place in these seven months (Table S1). The data were checked for any errors and outlying values while data from incomplete years were removed. In some cases the daily solar radiation data were not available and were estimated by the method proposed by Ball et al. (2004). For the location Breda, the observed solar radiation and estimated from the method of Ball et al. (2004) produced a coefficient of determination (R^2) of 0.85 when compared for 10,000 data points.

2.2. Generating long-term daily weather data

Long-term, i.e., 50 years, daily weather data (maximum and minimum temperature, solar radiation and rainfall) required for crop modeling studies were generated using Long Ashton Research Station Weather Generator (LARS-WG) and MarkSim. These weather generators incorporate stochastic numerical models to produce time series of daily weather variables that aim to mimic the observed weather variables based on the statistical properties. While LARS-WG requires some years of historical climate records i.e., daily observed weather data to first calibrate before embarking on long-term weather data generation, MarkSim requires only site parameters viz., latitude, longitude and altitude to fit the model from interpolated surfaces in order to generate long-term weather data. The schematic framework of process of weather data generation and its subsequent use in crop modeling studies in assessing impact of climate change (CC) is shown in Fig. 1.

2.3. The Long Ashton Research Station — Weather Generator (LARS-WG)

LARS-WG (Semenov and Barrow, 1997) is a semi-parametric or empirical stochastic weather generator that uses series approach as described by Racsko et al. (1991). Version 5.5 of LARS-WG was used for this study. LARS-WG produces synthetic daily time series of maximum and minimum temperatures, precipitation and solar radiation by using available observed daily weather data for a given site to determine a set of parameters for probability distributions of weather variables as well as correlations between them. The weather generator distinguishes wet and dry days depending on whether the precipitation is greater than zero. The occurrence of precipitation is modeled by alternating wet and dry series approximated by semi-empirical probability distributions (Semenov and Brooks, 1999). On a wet day the amount of precipitation is modeled using semi-empirical distributions for each month.

Minimum temperature, maximum temperature and radiation are related to the amount of cloud cover, hence LARS-WG uses separate wet and dry day distributions for each of these variables (Semenov et al., 1998). The normal distribution is used for the temperature variables with the mean and standard deviation varying daily according to finite Fourier series of order 3. Semi-empirical distributions with equal interval size are used for solar radiation (for further details see