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Simulating peanut (*Arachis hypogaea* L.) growth and yield with the use of the Simple Simulation Model (SSM)

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ABSTRACT

The use of crop simulation models for interpreting experiments and analyzing production systems in different management and environmental conditions is common in the literature. In this study, parameterization and evaluation of the Simple Simulation Model (SSM) for the prediction of peanut (*Arachis hypogaea* L.) growth and yield was conducted for the first time. Data from different field experiments from Astaneh Ashrafieh of northern Iran were used for coefficient estimation and model evaluation for the Virginia-type peanut variety North Carolina 2 (cv. NC2). After estimation of genetic parameters, the model was tested using independent data. The SSM simulated peanut growth and yield with reasonable accuracy, using data of more than 10 field experiments from different environmental conditions (11 experiments in the parameterization stage and 15 experiments in the evaluation stage). Based on data of independent experiments that were not used for parameterization, the model predicted an acceptable percentage of the observed results concerning days to harvest maturity (r = 0.46, CV = 5%), accumulated dry matter (r = 0.66, CV = 15%), grain yield (r = 0.55, CV = 21%), and pod yield (r = 0.45, CV = 18%). Local sensitivity analysis with 23 parameters indicated that two parameters related to leaf development and a parameter related to yield formation were the most sensitive cultivar-specific parameters; thus, estimation of the parameters need to be done with care for new cultivars. The SSM provided an adequate level of peanut growth simulation and based both on its transparency and easiness-to-use can be used as a valid tool for simulating growth of peanut Virginia-type varieties.

1. Introduction

Peanut (*Arachis hypogaea* L.) is one of the most important oilseed crops in the tropics and subtropics, grown for the production of oil (peanut seed contains 43–55% oil and 25–28% protein) (Smartt, 1994; Maiti and Ebeling, 2002). The area under peanut cultivation in the world is 24.07 million ha, of which 11.45 million ha are in Asia. The global production of peanut pods is 37.64 million tonnes annually (FAO, 2010). Peanut cultivation in Iran covers an area of about 3500 ha (Noorhosseini et al., 2016), of which 2800 ha are in Guilan Province in northern Iran. Astaneh Ashrafieh, with 2507 ha under peanut cultivation and average pod yield of 3800 kg per ha in 2016, is the largest region of peanut production in Iran (Agricultural Jihad, 2016). Most of the product is consumed directly and, therefore, the total production cannot meet the domestic demand; consequently, imports from some peanut-producing countries, such as Iraq and China, take place.

So far, numerous attempts have been made using field and laboratory experiments to better understand factors affecting crop yield per unit area, but field experiments cost a lot to developing countries for identifying factors that contribute to crop production increase, especially for industrial crops. Hence, many researchers have considered crop simulation models as an easy and cheap method for identifying factors that contribute to crop yield increase (Soltani and Hoogenboom, 2007). Since in many countries the low yield is a result of a yield gap, crop simulation models can successfully be used to evaluate regional production potential and yield gap (Soltani, 2009). Peanut as an industrial crop is not an exception. Simulation models can be of high importance through identifying useful traits in different varieties concerning plant breeding and thus by assisting farm management in decision-making (Meinke and Hammer, 1995). In addition to understanding crop reaction to water availability, soil, plant, and climate (Soltani, 2009), simulation models can be used to evaluate physiological traits that can optimize yield using the available resources (Soltani et al., 2006).

Some models that have been used for simulation of peanut growth, development, and yield are: the CSM-CROPGRO-Peanut model, which is included in the Decision Support System for Agrotechnology Transfer (DSSAT) (Jones et al., 2003), the APSIM (Keating et al., 2003), and the

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CropSyst (CROP System) (Stockle et al., 1994). In addition to the above models, another model, called SSM, has been proposed by Soltani and Sinclair (2012) to simulate growth of different crops. This model has considerable advantages compared with other models, e.g., one can easily use an Excel spreadsheet to provide input and produce output and also it is of open source. Moreover, the model does not need as many parameters for phenology simulation or dry matter production and distribution as other models. Soltani and Sinclair (2015) compared four models, i.e., SSM, CropSyst, APSIM, and DSSAT for predicting wheat yields and concluded that the SSM was able to predict growth, development, and yield of wheat with more robustness than the other models. Also, the number of input parameters was much lower in the SSM (55 parameters) compared with the APSIM model (292 parameters) and the DSSAT model (211 parameters). The SSM has been parameterized and evaluated for simulating the growth of several crops. SSM-iLegume-Soybean, SSM-iLegume-Chickpea, SSM-iMaize, SSM-iSorghum, and SSM-iWheat are the most important sub-categories of this model. The SSM-Soybean showed acceptable performance for important crop features, including days to flowering and harvest maturity, main stem node number, and grain yield (Nehbandani et al., 2015). The SSM-iWheat successfully simulated phenological stages (days to anthesis and harvest maturity), leaf area index (LAI), dry matter at anthesis, total dry matter at harvest maturity, and grain yield (Maddah, 2014). The SSM-Chickpea successfully simulated physiological days (i.e., number of days under optimum temperature and photoperiod conditions) and phenological stages, including emergence to flowering, flowering to first-pod, first-pod to beginning seed growth, and beginning seed growth to harvest maturity (Soltani et al., 2006). Moreover, acceptable simulation of chickpea grain yield with the SSM for a wide range of environmental conditions has been reported (Soltani and Sinclair, 2011).

With regard to peanut, Halilou et al. (2016) estimated the SSM coefficients only for simulating leaf area and reported that relevant coefficients with different genotypes were acceptable. Moreover, some coefficients of the SSM for peanut were presented by Soltani and Sinclair (2012). However, in general, no parameterization and evaluation has been done with the SSM for simulating peanut growth and yield in Virginia-types of peanut. Therefore, the objective of this study was to parameterize and evaluate the SSM for the prediction of peanut growth and yield based on data of independent field experiments conducted in Astaneh Ashrafieh, northern Iran.

2. Methodology

2.1. Study site and observed climate data

The study was carried out in Astaneh Ashrafieh (lat. 37°16′ N, 49°56′ E, altitude about 3 m), including Central District and Bandar-e Kiashahr, near to the Caspian Sea in northern Iran in 2015. Meteorological data for this study was provided from Bandar-e Kiashahr, Bandar-e Anzali (alongside the coastal line of Bandar-e Kiashahr synoptic station), and Lahijan (adjacent to the central district of Astaneh Ashrafieh) synoptic stations. Geographical information and average descriptive statistics of the long-term meteorological data of this region according to these three stations are provided in Table 1.

2.2. Field experiments

In order to simulate peanut growth, development, and yield (variety North Carolina 2, cv. NC2, a Virginia-type commercial peanut variety with large pods and seeds, accounting for most of the peanuts roasted and eaten as inshells) using the SSM, data from different field experiments in Astaneh Ashrafieh were used for parameterization and evaluation. These experiments are reported in Table 2.

2.3. SSM structure

The SSM was used to simulate growth, development, and yield of peanut in the current climate conditions (Soltani and Sinclair, 2012). The model is of open source and it can help analyzing the production of this crop, taking into account genetic, environmental, and managing limitations. This model can simulate phenological stages, development and senescence of the leaves, dry matter distribution, plant nitrogen (N) budget, yield formation, and soil water balance. The response of plant processes to environmental factors, like solar radiation, photoperiod, temperature, N, available water, and genetic differences of varieties in this model was considered.

The SSM simulates phenological stages as a function of temperature, photoperiod, and water shortage stress. Development and senescence of the leaf area is a function of temperature, available N for leaf growth, plant density, and remobilization of N. Production of dry matter is estimated as a function of received radiation and temperature. The distributed dry matter is based on development stage and start-end point relations between vegetative organs (leaf and stem) and seed. This model conducts the simulation on a daily basis and uses available water, weather, and soil data. In this model, different stages of phenology include emergence, beginning bloom (R1), beginning pod (R3), beginning seed (R5), physiological maturity (R7), and harvest maturity (R8) that are predictable according to the required biological day for each stage of development (Soltani et al., 2006). Abbreviations for all parameters used in the model are presented in Table 3.

2.4. Phenology

Determination of phenological stages in the SSM is based on biological days (the minimum number of days needed to complete a certain development stage at a given temperature, photoperiod, and optimum humidity) (Soltani and Sinclair, 2012). The value of biological days (BD) is calculated by multiplying photoperiod and temperature function according to Eq. (1):

$$BD = f(T) \times f(P) \tag{1}$$

In this equation, $f(T)$ and $f(P)$ are temperature and photoperiod functions, respectively, showing the relative speed of development at a certain temperature and photoperiod compared with the optimum conditions. Development of a stage occurs when biological day on phenological stage reaches a specific degree for that stage (Soltani and Sinclair, 2012).

Reaction of the development rate to temperature in most crops, including peanut, can be described using a 3-segment linear function (Soltani, 2009). The required parameters in this function include mean daily temperature (TMP, °C) lower than the base temperature (TBD, °C),

Table 1
List of synoptic stations of investigated locations with latitude, longitude and altitude.

Station	Latitude (°N)	Longitude (°E)	Altitude (m)	Baseline period	Mean temperature (°C)		Rainfall in year (mm)	Solar radiation (sunny h)
					Minimum	Maximum		
Kiashahr	37°23′	49°53′	−22.0	2007–2015	13.23	20.47	1302.56	4.77
Lahijan	37°12′	50°01′	34.2	2005–2015	12.02	21.06	1383.06	5.04
Anzali	37°29′	49°53′	−23.6	1992–2015	14.29	19.15	1718.20	5.25