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MODELING GROWTH AND YIELD OF SUNFLOWER (*HELIANTHUS ANNUS* L.)

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Abstract

Sunflower (*Helianthus annus* L.) is one of the most important oil seed crops in Iran. In spite of very progressing in production mechanization and varieties breeding, weather is still one of the most important determining factors for growth and production crops. Under optimal water and nutrient supply, radiation and temperature are two important factors for determining of production and dry matter accumulation. Quantification of the effect of radiation and effect of temperature on growth and yield of sunflower is important in selecting this crop for different agro-climatic situation. Environmental limitations in production at each regional can be evaluated using a crop simulation model and prolong weather data. The model operates simulation daily and it has four segments include simulation of leaf area index, light interception, dry matter production and seed yield. For testing model, the capability of the model was determined to predicting of leaf area index and accumulated dry matter production. Paired data of observed and simulated for both leaf area index and accumulated dry matter were tested by t test. Between paired data were not significant ($\alpha = 0.05$). Also linear regression between observed and simulated values for leaf area index and accumulated dry matter explained more than 95% of variability.

Key Words: Modeling; Sunflower; Growth; Dry Matter.

Introduction

Sunflower (*Helianthus annus* L.) is one of the most important oil seed crops in Iran. In spite of very progressing in production mechanization and varieties breeding, weather is still one of the most important determining factors for growth and production crops. Under optimal water and nutrient supply, radiation and temperature are two important factors for determining of production and dry matter accumulation. In fact in this condition, radiation and temperature are limiting factors. Quantification of the effect of radiation and effect of temperature on growth and yield of sunflower is important in selecting this crop for different agro-climatic situation. Environmental limitations in production at each regional can be evaluated using a crop simulation model and prolong weather data. Therefore when the water and nutrient elements are not limiting factors for plant growth, maximizing intercepting solar radiation during growth season has major important. Therefore selecting suitable planting pattern is important. Also providing requirement thermal time for planting cultivar is necessary at each regional. Models serve as good tools for such decisions [1]; [2]; [3].

Several simulation models have been developed for the sunflower [4-7]. The above models describe plant processes at various degree of complexity which need to be calibrated before testing in other countries. The present study was aimed to develop a very simple model for simulating sunflower growth and yield for using analysis of effects of climate and agro-management under optimal conditions.

Materials and Methods

The model operates simulation daily and it has four segments include simulation of leaf area index, light interception, dry matter production and seed yield. All parameters value, inputs and outputs and abbreviation words in the model are given in Table 1.

Leaf growth

In this model approach was followed, based on the LAI at maximum growth rate and the relative length of the four different crop development stages, defined by the

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FAO and the International Institute for Applied Systems Analysis [8]. Thermal time or growth degree day controls these different crop development stages. Hence, growth degree day concept was used to quantifying development stage, with a base temperature (Tb) and critical temperature (Tc) as:

$$GD = Tb \text{ if } T < Tb$$
$$GD = T-Tb \quad \text{if } T > Tb \qquad (1)$$
$$GD = Tc \quad \text{if } GD > Tc$$

Where DTT is the thermal time each day (˚Cd) and T is average daily temperature. Growth degree day (GDD) was calculated by accumulating GD after emergence.

With respect to leaf growth rate, four growth stages have been distinguished.

Stage 1: This stage, starts from emergence to the end of the vegetative stage, is referred to the period of fast linear growth during which the LAI increases at a constant rate and calculated by below equation:

$$LAI_{(i)} = (LAImax/GDD_1) * (GDD_{(i)}) \text{ if } GDD_{(i)} \leq GDD_1 \quad (2)$$

Where LAImax equals the LAI at maximum growth rate and GDD_1 represents the accumulated thermal time from emergence till the end of first stage.

Stage 2: From this stage, more and more assimilates are used to produce reproductive organs, and leaf development continues with a constant trend, but reduces until midseason when the LAI at full canopy development (LAIfull) is attained. The LAIfull has been estimated by LAImax + 0.5. Consequently, the rate which the LAI increases during this linear lag period equals to:

$$LAI_{(i)} = (LAIfull - LAImax) / (GDD_2) * (GDD_{(i)}) + LAImax \quad (3)$$

$$\text{If } GDD_1 \leq GDD_{(i)} \leq GDD_2$$

Where GDD_2 represents the accumulated growth degree day from emergence till the end of stage 2.

Stage 3: Leaf growth stops from this stage until all assimilates are used for the development of flowers and seeds. To the end of the stage 3, all leaves are actively participating in this biomass production, and the LAI remains constant.

$$LAIi = LAIfull \text{ if } GDD_2 < GDD_{(i)} \leq GDD_3 \quad (4)$$

Stage 4: Start of stage 4 or the maturation stage marks the leaf growth stage of exponential decay characterized by an exponentially decreasing leaf area due to leaf senescence. Penning de Vries and van Laar (1982) estimated the relative leaf death rate during this stage at 3% per day:

$$LAI_{(i)} = LAI_{(i-1)} - (0.03*LAI_{(i-1)}) \text{ if } GDD_{(i)} > GDD_3 \quad (5)$$

$$\text{If } GDD_{(i)} = TGDD \text{ then End}$$

Where $LAI_{(i)}$ ($m^2. m^{-2}$) and $LAI_{(i-1)}$ ($m^2.m^{-2}$) are the actual LAI and the LAI of the previous day, respectively.

Light interception

Crop production often shows a linear relation to cumulative radiation [9] or, more generally, to cumulative intercepted radiation [10]. Consequently, models have been developed for biomass production are linearly related to intercepted radiation. Detailed numerical simulation of the radiation absorption (ASRAD: radiation absorption by the overlying LAI) has shown that its approximated by:

$$ASRAD = (1-\rho) SRAD (1- EXP (-K * LAI)) \quad (6)$$

In which ρ is canopy reflection coefficient, SRAD equals the average daily solar radiation ($Mj.m^{-2}.d^{-1}$) and K stands for the extinction coefficient. Typical values for K are in the range of 0.5 to 0.8. Value of K was considered 0.8 [11]. Also value of ρ was considered 0.07 [12].

It is excellent, and never deviate more than 1 or 2% from a detailed simulation with sunlight and shaded leaves [12].

Dry matter production

The growth rate of the crop (CGR, $g.m^{-2}d^{-1}$) is calculated as a function of radiation use efficiency (RUE), solar radiation (ISRAD, $Mj.m^{-2}d^{-1}$), total LAI, and a temperature correction factor (TCF):

$$CGR=ASRAD*RUE*TCF \quad (7)$$

The value of RUE for sunflower was reported 1.05 $g.Mj^{-1}$ [13]. The value of RUE was modified by the average daily temperature according to the response of dry matter production to temperature [14]. This effect was incorporated by multiplying RUE by a temperature correction factor .The value of TFC is 1 within a range from 17 to 37 ˚C average daily air temperature and is linearly decreased to 0 from 17 down to 0 ˚C and from 37 to 47 ˚C.

Total dry weight increment (TDM) for each day is calculated as:

$$TDM_{(i)} = TDM_{(i-1)} + CGR_{(i)} \quad (8)$$

Where: $TDM_{(i-1)}$ is accumulated DM at previous time step (g DMm^{-2}).

Seed yield

During seed filling, seed dry matter (SDM) may be considered as the product of total above ground vegetative dry matter (TDM) and harvest index (HI).

Sridhara and Prasad [15] reported that the HI of sunflower increased linearly with time throughout seed filling and the rate of increase in HI (DHI) was 0.011 day^{-1}. Seed yield for each day (SDM) is calculated as:

$HI_{(i)} = HI_{(i-1)} + DHI$ if $GDD_{(i)} > 1800$ then (9)

$SDM = TDM_{(i)} * HI_{(i)}$

Where 1800 is requiring growth degree day for starting seed filling.

Input and output of model

The model requires data weather information (daily minimum and maximum temperature and solar radiation), crop management (planting date) and plant characteristics (base temperature, low and high optimum temperature, ceiling critical temperature, radiation use efficiency, extinction coefficient and harvest index) and inputs (accumulated growth degree day for different growth stage and maximum leaf area index) that showed in table 1. Outputs of model are maturity time, daily leaf area index, daily crop growth rate, accumulated dry matter production and seed yield.

Table1. List of abbreviations of model inputs and outputs

Abbreviation	Explanation	Unit	Value
T	Daily average temperature	˚C	input
Tb	Base temperature	˚C	7
Tc	Critical temperature	˚C	47
GD	Growth degree day	˚C d	---
GDD	Accumulated growth degree day	˚C d	---
TGDD	Total accumulated growth degree day	˚C d	3500*
GDD_1	Accumulated growth degree day from emergence to the end of the stage1	˚C d	1720 *
GDD_2	Accumulated growth degree day from emergence until the end of stage 2	˚C d	1900*
GDD_3	Accumulated growth degree day from emergence to start of the maturation stage	˚C d	2630*
LAI	Leaf area index	m^2m^{-2}	----
LAImax	Maximum leaf area index	m^2m^{-2}	3.2*
LAIful	LAImax + 0.5	m^2m^{-2}	3.7*
SRAD	Solar radiation	$mjm^{-2}d^{-1}$	input
ASRAD	Absorption of solar radiation	$mj\ m^{-2}\ d^{-1}$	
RUE	Radiation use efficiency	g/Mj	1.01
k	Extinction radiation		0.8
TDM	Total dry matter	$g\ m^{-2}$	output
CGR	Crop growth rate	$g\ m^{-2}\ d^{-1}$	output
HI	Harvest index	-----	output
DHI	Rate of increasing HI	g day^{-1}	0.011
SDM	Seed yield	$g\ m^{-2}$	output

Test of model

For testing model, the capability of the model was determined to predicting of leaf area index and accumulated dry matter production. In order to determining capability of model, leaf area index and plant dry matter were measured each 10 days intervals. Then by using of model was generated same data for like days. Coupled data was tested by using coupled t test. Also coefficient determination (R^2) was determined for measured and simulated data by linear regression.

Environmental characteristics

University of Mohaghegh Ardabili research station was located at 36° N and 37° E and at an altitude of 1200 m. The soil texture in study site was loam silt. Average daily temperature varies between 14.4 and 34.4° C and also average daily radiation varies between 9.4 and 28.09 $Mj.m^{-2}.day^{-1}$.

Crop characteristics

In order to achieving of crop characteristics (length of growth duration, length of relative growth development stage and maximum leaf area index), Golshid cultivar cultivated in University of Mohaghegh Ardabili research station on 30 April in 2008. Length of growth duration lasted for 121 day. First growth stage characterized by from emergency until full ground cover lasts for 60 day. Second and third stage includes flowering and seed formation, last for 30 day. During a 31 day forth growth stage, the seeds ripen and dry. For calculating LAI and CGR, four plants were sampled each 10 day. Full canopy developed had leaf area index equal 3.7.

Results and Discussion

Outputs of model are daily leaf area index, crop growth rate and accumulated dry matter. Measuring and predicting leaf area index values are showed in figure1. Golshid had LAImax and LAIfull equal 3.2 and 3.7 respectively. Predicting accumulated dry matter values with along measuring accumulated dry matter are showed in figure 2.

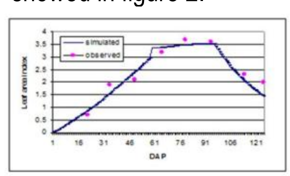

Fig. 1. Time trends in simulated (--) and observed (·) leaf area index throughout season

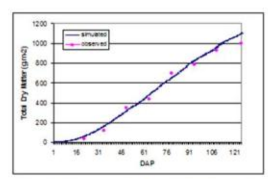

Fig. 2. Time trends in simulated (--) and observed (.) dry matter

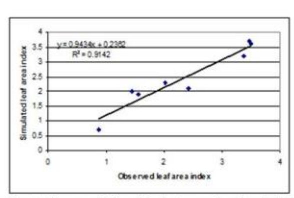

Fig. 3. Linear relationship between the simulated and observed leaf area index throughout season

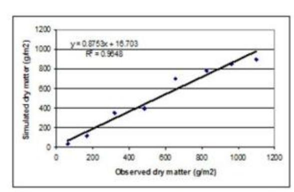

Fig.4. Linear relationship between the simulated and observed leaf area index throughout season

The trends in observed and simulated values for leaf area index and accumulated dry matter showed a good agreement at different growth stage. This suggests that the relationships and parameters used in the model described the growth and yield of sunflower (cv. Golshid) adequately.

Paired data of observed and simulated for both leaf area index and accumulated dry matter were tested by t test. Between paired data were not significant (α =0.05). Also linear regression between observed and simulated values for leaf area index and accumulated dry matter explained more than 95% of variability (figure 3&4). There was a good agreement between the simulated and the observed leaf area index and accumulated dry matter indicating the ability of the model to predict the growth yield to Golshid cv.

The presented model is suitable for use in simulation studies of potential yield of Golshid cv and production limitations (radiation and temperature).

In conclusion, the adaptation and evaluation of this model under optimum condition appeared reasonable and suggested interesting prospects for prediction of sunflower seed yield for different cultural practices, such as sowing date. The required weather input data are generally available and the structure of the model permits simple parameter changes so that it can be used to simulate the growth and development of other sunflower genotype in other locations. However, the model needs to be validated using more observations on range of sunflower genotypes and on sites that have different growing conditions.

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