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REGULAR ARTICLE

A VERY SIMPLE MODEL FOR SIMULATING SUGAR BEET YIELD FOR POTENTIAL PRODUCTION

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SUMMARY

Sugar beet is one of the most important crops in Iran. The potential yield and its limitations can be estimated using a simple model and long-term weather information. The present study was aimed to develop a very simple model for sugar beet. this model is a dynamic and mechanistic simulation model to simulate sugar beet growth and sugar accumulation for potential production condition. Therefore when the water is not a limiting factor for plant growth, maximizing intercepting solar radiation during growth season has major important. Because in this condition, solar radiation is a limiting factor for plant growth. Therefore selecting suitable planting date is important. Crop simulation models help us to determine planting date and to asses risk production. The model uses a few relationships to define leaf area development as a function of accumulated thermal time units. Biomass accumulation was simulated as a function of fraction of photosynthetically active radiation interception and radiation use efficiency. The growth of root is dependent on the biomass accumulation. The model uses a daily time step and readily available maximum and minimum temperatures and solar radiation. The model was tested for different planting dates at Ardabil in Iran. The model performed satisfactory in predicting the leaf area index and root biomass of sugarbeet as influenced by potential production condition. The simulated average root yield and leaf area index and its range were similar to observed root yield and leaf area index (root mean square error for root yield and leaf area index were equal to 3.97 t ha^{-1} and 1.3 respectively).

Keywords: Leaf area index, Root yield, Simulation, Sugar beet.

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1. Introduction

Sugar beet is an important industrial crop which is grown in irrigated conditions. In the most regions of sugar beet growing lands in Iran such as Ardabil, Sugar beet can be annually cropped alone or as a first crop. Therefore providing required thermal time in each region is important. Quantification of the effect of thermal time and solar radiation on growth and yield of sugar beet is important for selecting this crop to different agro-climatic situations. Lately, crop simulation models have been developed to predict the growth and yield of different crops under different agro-climatic conditions. These models also serve as a management decision tools [1]; [2]; [3]. Several simulation models have been developed for the sugar beet [4]; [5]. These models describe plant processes at various degrees of complexity which need to be calibrated before testing in the other countries. Hence, an attempt was made here to prepare a very simple model based on both mechanistic and empirical perspectives according to Daicros [6] and Sbeet [7] with a daily time step that simulates the response of sugar beet to temperature and solar radiation. Some of the relations and parameters are derived from above models. The present study was aimed to develop a very simple model for sugar beet. The aims of model such as: 1- Using of this model for analyzing yield response of sugar beet to weather change specially temperature and radiation. 2- Using of this model for planting date determination to achieve suitable spectrum of planting dates.

2. Material and methods

A field experiment was conducted to develop and evaluate a simulation model for predicting the growth and root yield of sugar beet as influenced by planting date.

Experiment:

Field experiment was conducted during the spring and summer seasons in 2006 at the Agricultural Research Station in Ardabil. The soil was clay loam with low fertility and pH 6.7. The treatments were four planting dates (9, 19, and 28 April and 8 May). The experiment was laid out as randomized block design with four replicates. The sugar beet cv. Rasol was sown with 50 x 30 cm spacing distances after the conventional cultivation practices.

Collection data:

Daily minimum and maximum temperature data were obtained from weather station in the vicinity of the experimental site. The amount of solar radiation was calculated by Angestrom equations. The data on leaf area, total and root biomass were recorded at fifteen-day intervals starting from 15 days after planting in experiment.

Model cescription:

Under favorable growing conditions, incoming solar radiation and temperature are the two main factors determining the dry matter increase and sugar accumulation.

The combination model was derived based on relatively few conservative relationships developed from the mechanistic perspective [7]; [8] and [9] .It involved four modules viz., simulation of leaf area, light interception, dray matter production and partitioning dry matter. All the original parameter values in the SUBE growth 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 FAO and the International Institute for Applied Systems Analysis[10]. Thermal time controls these different crop development stages. Hence, thermal time concept was used to quantifying development stage, with a base temperature (Tb) and critical temperature (Tc) as:

$$DTT = Tb \quad \text{if } T < Tb$$
$$DTT = T - Tb \quad \text{if } T > Tb$$
$$DTT = Tc \quad \text{if } DTT > Tc$$

Where DTT is the thermal time each day (°Cd) and T is average daily temperature. Thermal time (TT) was calculated by accumulating DTT after emergenc.

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

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

$$LAIi = (LAI\ max / TT1) * (TTi) \text{ if } TTi \leq TT1$$

Where LAImax equals the LAI at maximum growth rate (m2 m-2) and TT1 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 root biomass, 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:

$$LAIi = (LAIfull - LAImax) / (TT2) * (TTi) + LAImax$$

$$\text{If } TT1 \leq TTi \leq TT2$$

Where TT2 represents the accumulated thermal time 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 root. To the end of the stage 3, all leaves are actively participating in this biomass production, and the LAI remains constant.

$$LAIi = LAIfull \quad \text{if } TT2 < TTi \leq TT3$$

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 [11] estimated the relative leaf death rate during this stage at 3% per day:

$$LAI(i) = LAI(i\text{-}1) - (0.03*LAI\ (i\text{-}1)) \quad \text{if } TT(i) > TT3$$

If TT(i) = GTT then End

Where LAIi (m2 m-2) and LAI(i-1) (m2m-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 [12] or, more generally, to cumulative intercepted radiation [13]; [14]. 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:

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

In which ρ is canopy reflection coefficient, SRAD equals the average daily solar radiation (Mjm-2d-1) and K stands for the extinction coefficient. Typical values for K are in the range of 0.5 to 0.8. The value of the canopy reflection coefficient (ρ) should be taken by measuring. If they are not available from measurements, the default values that can be used for K and P are 0.6 and 0.07 respectively [15]).

It is excellent, and never deviate more than 1 or 2% from a detailed simulation with sunlight and shaded leaves [15].

Dry matter production:

The growth rate of the crop (CGR, g m-2d-1) is calculated as a function of radiation use efficiency (RUE), solar radiation (ISRAD, Mj m-

2d-1), total LAI, and a temperature correction factor (TCF):

CGR=ISRAD*RUE*TCF

The value of RUE was modified by the average daily temperature according to the response of dry matter production to temperature [16] and [17]. This effect was incorporated by multiplying RUE by a temperature correction factor .The value of FTC is 1 within a range from 10 to 25 ˚C average daily air temperature and is linearly decreased to 0 from 10 down to 0 ˚C and from 25 to 35 ˚C.

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

TDM(i) = TDM(i-1) + CGR(i)

Where: TDM(i-1) is accumulated DM at previous time step (g DMm-2).

Dry matter partitioning:

The dry matter available each day for crop growth is partitioned into roots (sugar yield) as a crop-specific function of development stage. Allocation is first made to root. The remaining dry matter is allocated to the shoot.

The growth rate of root (RTG) is calculated based on the growth rate of the crop, fractions of allocated dry matter are as:

RTGi = CGRi * FRT

SHGi= CGRi – RTGi

Where FRT is the fraction allocated to root and SHG is the growth rate of the shoots.

Partitioning function (FRT) changes from 0 to 1 and given by:

FRT = h * TDMi / (1+ h * TDMi)

Where h is the root partitioning coefficient [18].

Accumulated dry matter root (RTDM, kgha-1) and shoot (SHDM, kgha-1) for each day is calculated as below:

RTDM(i) = RTG(i-1) + RTG(i)

SHDM(i)= SHG(i-1) + SHG(i)

Test of the model:

The model was tested by comparing simulated and observed data in conditions of Ardabil in Iran. The observed and simulated values for several sugar beet characteristics showed a good agreement. This suggests that the relationships and parameters used in the model describe the growth and root yield of sugar beet adequately.

3. Results and Discussion

Model predictions of the biomass and leaf area index at different growth stage are shown in figure 1 and 2.

The slope and intercepts of the linear regressions that fitted the simulated / observable relationships for each of year were not significant (p = 0.05) which explained more than 97% of the observed variability (table 2).

Time trends in root biomass accumulation and leaf area development figure 1and 2) showed that the simulated and measured value were close throughout the growing season. Model performance for root biomass and leaf area development was evaluated using the data from field experiments. A comparison of the simulated root yield and leaf area index with the measured value showed that the two were quite close to RMSE (root mean square error) of 3.95 t ha-1 for root yield at harvest (predicted RMSE = 3.93 and observed RMSE = 3.97) and 1.3 for leaf area index throughout season (predicted RMSE = 1.2 and observed RMSE = 1.4). A linear regression between the simulated and the measured value for both root yield and leaf area index also indicated the ability of the model to predict the root yield and leaf area index accurately (figure 3 and 4). There was a good agreement between the simulated and the observed root yield and leaf area index indicating the ability of the model to predict the growth and yield to a certain degree of accuracy.

It can be concluded that the combination model developed with the help of several conservative relationships existing between climatic parameter and plant growth will predict the growth and yield of sugar beet with a fair of accuracy under a different planting dates. This model can be used to predict the potential root yield of sugar beet cultivar Rasol in the other locations. The required weather input data is 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 sugar beet genotypes in the other locations. However, the model needs to be validated using more observations on a range of sugar beet genotypes and on sites that have different growing seasons.

Reference	Value	Unit	Explanation	Abbreviation
	input	˚ C	Daily average temperature	T
[5]	3	˚ C	Base temperature	Tb
[5]	25	˚ C	Critical temperature	Tc
		˚ C d	Day thermal time	DTT
		˚ C d	Accumulated thermal time	TT
	3200*	˚ C d	Gross accumulated thermal time	GTT
	1520 *	˚ C d	Accumulated thermal time from emergence to the end of the stage1	TT1
	1700*	˚ C d	Accumulated thermal time from	TT2
	2420*	˚ C d	Accumulated thermal time from emergence to start of the maturation tage	TT3
		m^2m^{-2}	Leaf area index	LAI
	3*	m^2m^{-2}	Maximum leaf area index	LAImax
	3.5*	m^2m^{-2}	LAImax + 0.5	LAIful
	input	$mjm^{-2}d$-1	Solar radiation	SRAD
		mj m^{-2} d-1	Absorption of solar radiation	ASRAD
[19]	1.3	g/Mj	Radiation use efficiency	RUE
[20]	0.6		Extinction radiation	k
	output	g m^{-2}	Total dry matter	TDM
	output	g m^{-2} d-1	Crop growth rate	CGR
	output	g m^{-2} d-	Root growth rate	RTG
	output	g m^{-2}	Root dry matter	RTDM
	output		Root partitioning function	FRT
	1 output	g m^{-2} d-	Shoot growth root	SHG
	output	g m^{-2}	Shoot dry matter	SHDM
[18]		0.001	Root partitioning coefficient	h

Table 1. List of abbreviations, input parameters and values used in the model.
data resulted by field experiment.

Table2: linear regression of the predicted and observed root biomass for different planting date.

Planting date	a	b	r2	F
9 Apr	- 0.81 (1.02)	1.12 (0.05)	0.98	417
19 Apr	-0.20 (1.15)	0.93 (0.05)	0.97	296
28 Apr	-0.19 (1.00)	1.00 (0.05)	0.98	404
8 May	-0.40 (0.99)	1.01 (0.04)	0.98	419

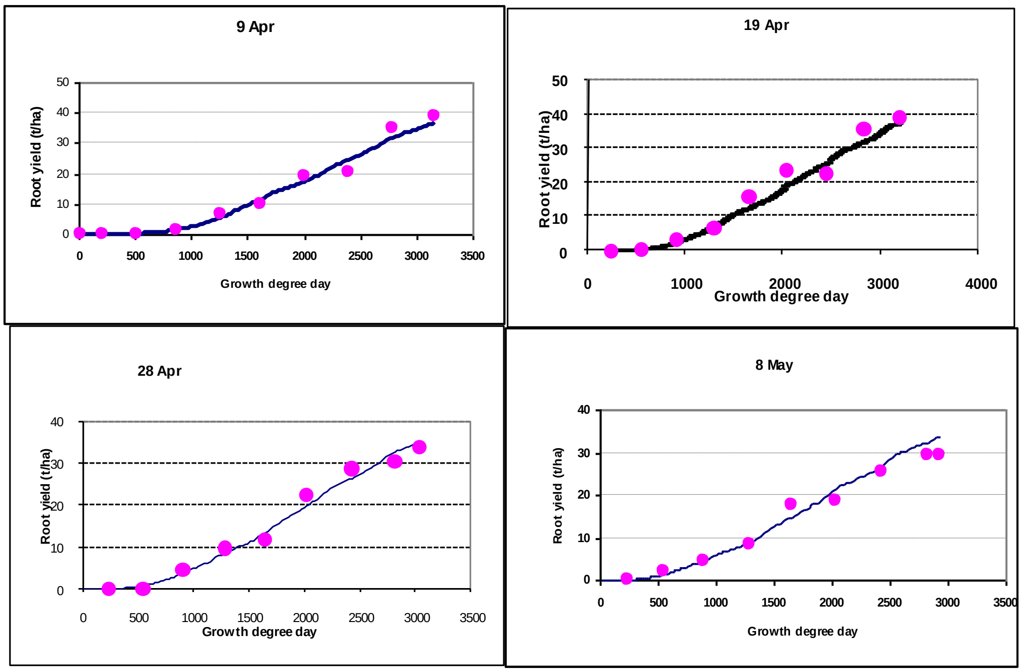

Fig. 1. Time trends in simulated (dashes) and observed (circles) root biomass as influenced by planting date.

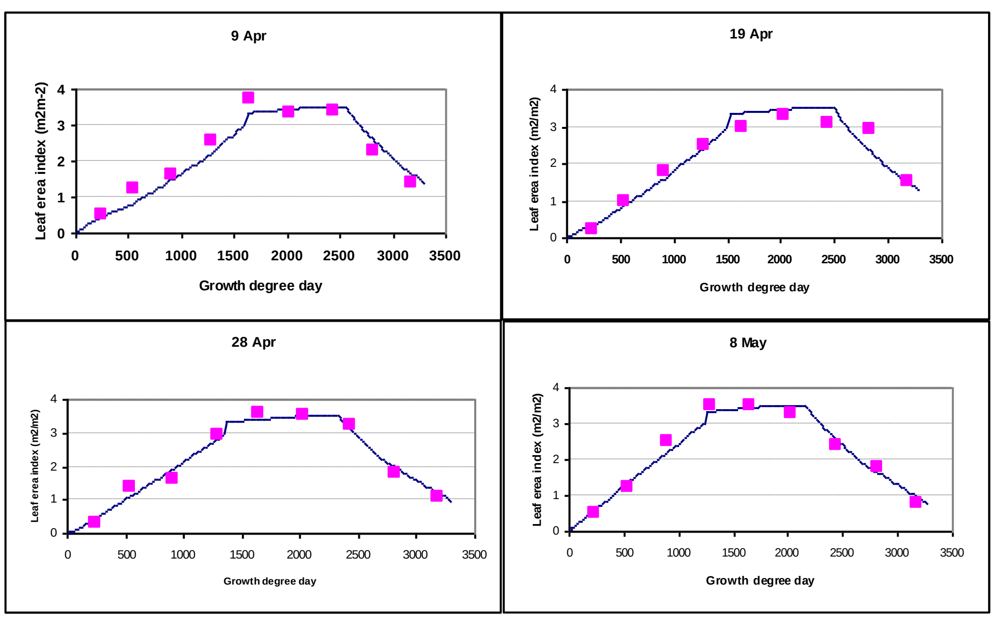

Fig. 2. Time trends in simulated (dashes) and observed (squares) leaf area as influenced by planting date.

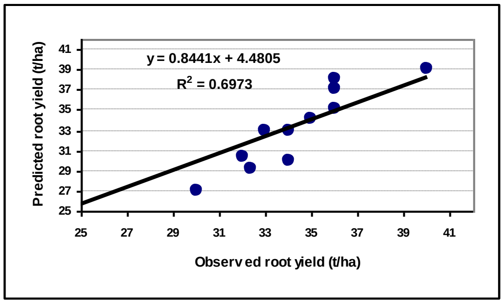

Fig. 3. Linear relationship between the simulated and observed root yield at harvest.

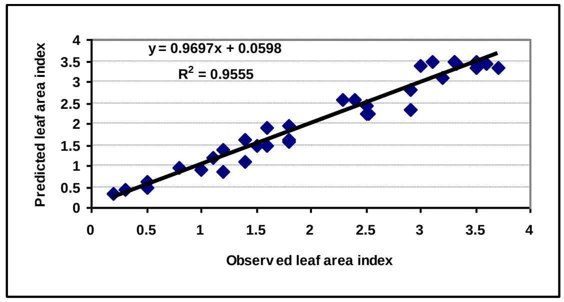

Fig. 4. Linear relationship between the simulated and observed leaf area index throughout season.

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