

To Simulate the Impact of Sequential Climatic Stresses on Soybean Using Infocrop Model



Agriculture

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ABSTRACT

Occurrence of floods and drought accompanied by high temperature in a single crop season are becoming detrimental to crop production in the climate change scenario. A simulation analysis was carried out using the InfoCrop-SOYBEAN model for testing the ability of model to simulate the crop performance under sequential stresses after calibrating it with rainfed and supplemental irrigation control conditions. The observed values from experiment where soybean crop was exposed to excess water, drought and high temperature in five different combinations at different phases of crop growth were compared with those of simulated ones using statistical indices like model bias error, root mean square error and model efficiency. The model is efficient in simulating the phenology of crop exposed to multiple stress while requires improvement for simulating the dry matter and yield for simulating the crop performance under sequential stresses.

INTRODUCTION

Agriculture in many tropical countries, especially in south Asia, is at cross roads facing tremendous new challenges due to population growth and stagnation in farm level productivity in intensive farming areas. (Aggarwal, 2003). Crop modelling is defined as the science and art of mimicking the growth and development of the crop. A model is a simplified representation of a system. Crop models are useful in defining research priorities, technology transfer, yield estimation, as well as for predicting the effects of climate change and climatic variability. A well validated crop simulation model can simulate crop growth, development and yield with reasonable accuracy and serve as a viable tool for optimizing crop production. The use of modelling tool is gaining importance day by day due to increasing resource crunch and its capability to supplement field experimentation. Simulation is building of mathematical model and the study of their behaviour in reference to that of the system they represent. The models integrate the effects of different factors on productivity and have been used to determine the production potential, optimize crop management, quantify yield gaps, and to study the consequences of climatic variability and climatic change (Kropff et al., 1996, Berge et al., 1997, Tsuji et al., 1998 and Matthews and Stephens, 2002, Matthews and Stephens, 2002). InfoCrop is a generic crop model developed to meet specific requirements (Aggarwal et al., 2006). The basic model is written in Fortran Simulation Translator programming language (FST/FSE; Graduate School of Production Ecology, Wageningen, The Netherlands; Van Kraalingen, 1995), also recommended by the International Consortium for Agricultural Systems Applications (ICASA) as a standard languages for systems simulation (Jones et al., 2001). The model requires input data on weather, soil characteristics, details of crop management, population/severity of pests and varietal coefficients. Its general structure is based primarily on SUCROS (van Laar et al., 1997) and further supported by MACROS (Penning de Vries et al., 1989), WTGROWS (Aggarwal et al., 1994), and ORYZA1 (Kropff et al., 1994) models.

In India, pulse and oilseed crops are mainly grown during kharif season exposing these crops to various climatic stresses. These crops generally are grown in marginal lands or with fewer inputs. Thus, it is essential to quantify the impact of climate related multiple stresses on these crops to derive suitable adaptation measures. Soybean has been an emerging crop because of high concentration of protein (36%), oil (18%), and carbohydrate (20%) and is the third most important oilseed crop in India, after groundnut and mustard (Agricultural Statistics, 2013).

Robust modelling for simulating the impacts of multiple stresses in a crop season will be highly useful for developing the adaptation strategies at regional level.

MATERIALS AND METHODS

To study the impact of multiple stresses on soybean crop, field experiment was conducted during kharif season of 2011, in Research Farm of Environmental Sciences Division, I.A.R.I, New Delhi. Soybean variety Pusa-9814 was sown in the kharif season in plots each of 2x2 m size. Field experiment was laid out in a homogenous field with treatments of excess water, drought and high temperature in five different combinations at different phases of crop growth. In order to test the model performance in simulating the response of crop to multiple stresses, InfoCrop-SOYBEAN model was used. In the model, water stress was determined as the ratio of actual water-uptake and potential transpiration. The stress was assigned a value of zero (maximum water stress) when soil water content was depleted, and linearly approached a value of 1.0 when actual water uptake approached potential evapotranspiration. A decrease in soil water availability reduces the rate of germination. This was simulated by increasing thermal time depending upon available water fraction (AWF) in surface layer of soil. Similarly flooding stress is also taken in to consideration. Soil is considered water logged if there is free-standing water on soil surface or if the available water fraction of the surface layer is at least 20% higher than the field capacity.

For the initial calibration of model, the experimental values of pertaining to first two treatments viz., rainfed and irrigated were used. Initially, the model was calibrated for varietal performance using the varietal characteristics. For attaining the proper phenology, LAI, dry matter and yield, several iterations were done and simulations runs were made. Thereafter, the model inputs were changed as per the sequential stress conditions and simulations were carried out. Three statistical measures and indices were applied to evaluate the model that included mean bias error (MBE), root mean square error (RMSE) and modelling efficiency (ME).

$$MBE = \frac{1}{n} \sum_{i=1}^n (S_i - O_i) \quad RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^n (S_i - O_i)^2}$$

$$ME = 1 - \frac{\sum_{i=1}^n (S_i - \bar{O})^2}{\sum_{i=1}^n (O_i - \bar{O})^2}$$

Where n is the number of samples, S_i and O_i are the simulated and observed values, respectively, and \bar{O} is the mean of the observed data. The MBE indicates bias of model expressed % of overall mean. The RMSE describes mean absolute deviation between simulated and observed values. Accuracy of simulation is characterized by lower RMSE. ME allows negative values and compares de-

viation between simulated and observed state variables with the variances of observed values of development, growth and yield.

RESULTS AND DISCUSSION

Calibration of InfoCrop-SOYBEAN Model

The model parameters and interpolation functions were calibrated for soybean variety P-9814 from the field experiment data set. The observed data set on both irrigated and rainfed plants of both the crops from the field experiment were used for the calibration of the model.

From the result it was observed that the simulated phenology matched satisfactorily with the observed value (Table. 1). The simulated phenology matched that of observed one in rainfed crop. In irrigated crop, the phenology (days to 50% first flowering) delayed by 4 days. Observed values on yield was 1778 and 1926 kg per hectare while that of simulated were 1809 and 1884 kg/ha under rainfed and irrigated conditions, respectively while for the TDM, the observed values were 5206 kg/ha and 5742 kg/ha and that of simulated were 5307 kg/ha and 6184 kg/ha under rainfed and irrigated conditions respectively.

Table 1: Observed and simulated value of the calibration of Infocrop-Soybean model

Parameter	Rainfed		Irrigated	
	observed	Simulated	Observed	Simulated
Days to 50% first flowering	49	49	54	50
PFD (days)	47	48	48	47
Days to 50% PM	96	97	102	97
TDM (kg/ha)	5206	5307	5742	6184
Yield (kg/ha)	1778	1809	1926	1884

Simulating the crop response to multiple stresses

The validation was done for the phenology (days to 50% flowering (Fig.1), pod filling duration (PFD) (Fig.2), days to 50% physiological maturity (PM) (Fig.3) and total dry matter and yield. Days to 50% first flowering and pod filling duration simulated reasonably well by the model in the multiple stress treatments. The simulated values of days to 50% first flowering were higher in all the treatments except EW-DR-HT. While in the case of pod filling duration, the simulated values were same in the DR, and lower in all other treatments except DR-HT-EW.

Fig 1: validation result for days to 50% flowering in InfoCrop model

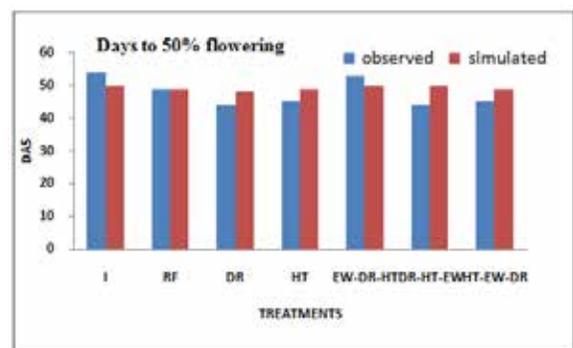


Fig. 2: validation result for pod filling duration in InfoCrop

model

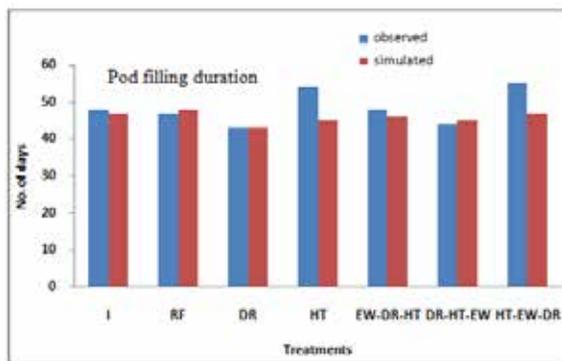
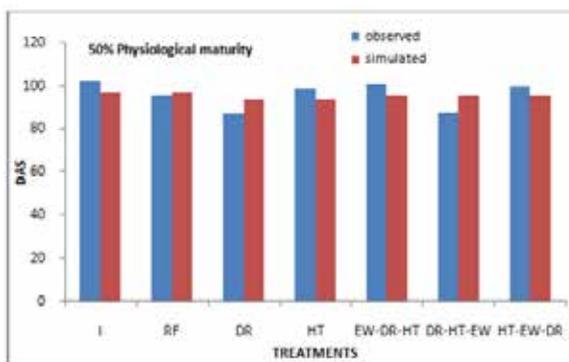


Fig. 3: Validation results for 50% physiological maturity in InfoCrop model



The time series performance model in simulating the response of soybean to sequential stresses indicated that the model over-estimated the TDM in vegetative phase in all the treatments irrespective of the type of stress occurring during this period. However, the model simulated the TDM at flowering phase fairly well in all the treatments. During pod filling period, model could simulate TDM matching observed only in one treatment where excess water coincided with pod filling period.(Fig.5) But it underestimated the TDM particularly during pod filling period under high temperature(Fig.4) and drought condition(Fig.6). However, the simulated yield was satisfactory with the observed one in all the three treatments with acceptable deviations

Fig. 4: Yield and TDM simulation in InfoCrop model for EW-DR-HT

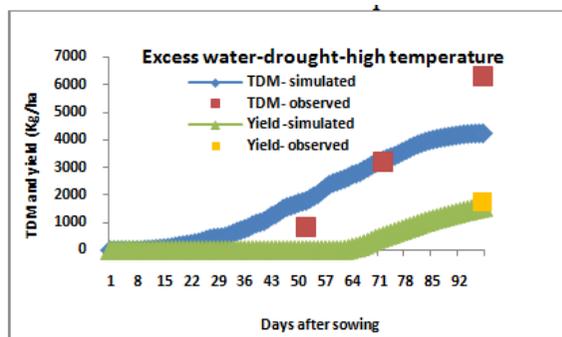


Fig. 5: Yield and TDM simulation in InfoCrop model for HT-

EW-DR

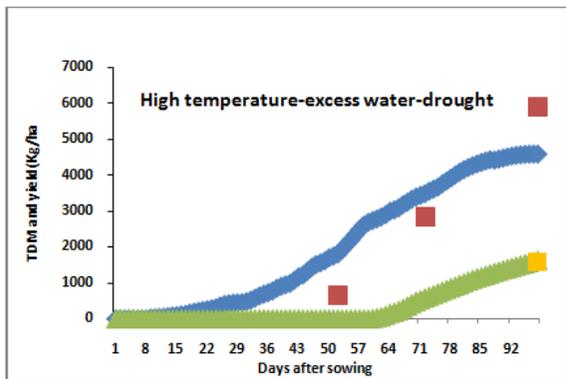
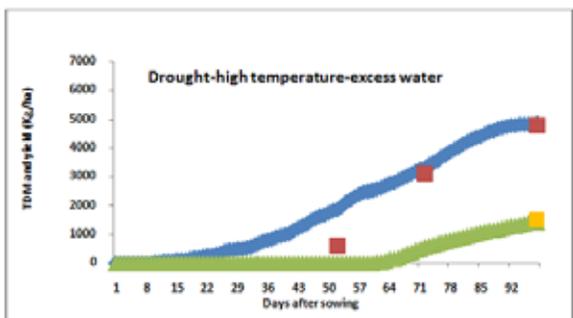


Fig. 6: Yield and TDM simulation in InfoCrop model for DR-HT-EW



Statistical performance of model

MBE showed the positive deviation between the observed and simulated value of days to 50% first flowering and yield, while it showed the negative deviation for pod filling duration, days to 50% physiological maturity and total dry matter (Table. 2). RMSE showed the accuracy of model (lower the RMSE value, higher the accuracy. Days to 50% first flowering, pod filling duration and days to 50% physiological maturity was simulated with greater accuracy as also indicated by the modelling efficiency (ME) values, while the total dry matter and grain yield was simulated with low accuracy.

Table 20: Statistical indices showed performance of Info-Crop-Soybean model

Parameters	MBE	RMSE	ME
Days to 50% flowering	1.57	3.94	0.98
Pod filling duration	-2.57	4.65	1.21
Days to 50% PM	-0.42	5.41	0.89
Total dry matter (kg/ha)	-535	978.63	0.04
Grain yield (kg/ha)	-27.71	135.71	0.58

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