

Impacts of Short-term Sequential Stresses on Maize (*Zea mays* L.) and its Simulation using Info Crop-Maize Model

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ABSTRACT

A field study was conducted with maize during monsoon season to quantify the response of maize to short-term sequential stresses related to floods and drought. A simulation analysis was also carried out using the InfoCrop maize model. The treatments of irrigated, rainfed, drought and four different combinations of sequential stresses (rainfed, irrigation and drought) at different phases of crop growth were imposed. Silking delayed by about one week under adequate irrigation regime, as compared to that of rainfed crop, however moderate drought advanced silking by 10 days. Grain yield was highest at the irrigated condition. Imposition of sequential stresses RF-D-EW, D-RF-EW, EW-RF-D, D-EW-RF and MD resulted in 46.7%, 51.7%, 35%, 40% and 63.3% decreased in grain yield respectively over irrigated condition. The total biomass was decreased with RF-D-EW, D-RF-EW, EW-RF-D, D-EW-RF and MD by 34.7%, 38.3%, 14.9%, 29.1% and 36.9% respectively. Maize model simulated days to 50% silking well in all situations of multiple stresses except in case where rainfed crop was exposed to excess water/flooding during flowering and then to terminal drought. The total dry matter and yield were also simulated satisfactorily in most of the cases. The InfoCrop maize model worked satisfactorily for rainfed and irrigated conditions and could be calibrated for the experimental conditions. However, refinement is needed from experimentation and model point of view for simulating the multiple and sequential stress situations.

Keywords

Climatic variability, Crop simulation model, Phenology, Growth, Yield.

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Introduction

Maize (*Zea mays* L) is considered to be important from the point of view of its nutritional role and commercial value. It is referred as queen of cereals and it has the highest yield potential (Tollenaar and Lee, 2006). Maize is the third most important cereal crop and contributes 78.2 Mt to world total food grain production with an area about 150 Mha (McCann, 2007; Parihar *et al.*, 2011). India is ranked sixth among maize producing countries with 9.4 Mha producing

23.29 Mt at a productivity of 2469 kg/ha (FAO, 2013). In India, maize is the third most important food crops after rice and wheat. It is grown mainly during monsoon season which covers 80% area.

Climate change is projected to increase the frequency of heavy rainfall events and alter rainfall distribution, with former causing water logging conditions and the later resulting in dry spell or drought conditions.

The flood and drought conditions may occur even in one season causing severe loss to the crop production. For instance, in India, in 2009, kharif season has experienced drought followed by flood situation in Andhra Pradesh, while in Bihar in 2010 kharif season first experienced flood followed by a long dry spell and then again flood situation. This caused immense loss to crop production. This situation implies that a crop may face multiple abiotic stresses in one season itself. More over the areas of cultivation of maize crop are either prone to drought or to floods. The impacts of drought and flood on crop growth and yield are multi-dimensional. Loss of turgidity, oxidative stress, loss of chlorophyll, hastening of leaf senescence, reduction in dry matter accumulation and poor seed set causes reduced yield in drought conditions (Prasad *et al.*, 2008). Similarly, in poorly drained soils, low oxygen is a common environmental stress experienced by plants during flooding. Flooding affects the root activity and thus, in most crop plants, water logging causes severe injury affecting plant growth and yield (Liao and Lin, 2001). Flooding also causes the physiological drought and lodging of crop. Even though a considerable understanding is made on the impact of individual effect of drought and flood on maize crop, there is very less information available on how crops respond upon exposure to multiple stresses like droughts and floods or excess water situations occurring in sequence in their life cycle. In the climate change scenario, where increased variation in rainfall is projected, occurrence of dry spells and heavy rainfall events in a crop season may prove to be more detrimental for crop production. Therefore, it is important to study the impact of multiple stresses on crop so as to prepare the adaptation strategies (Fagodiya *et al.*, 2011; 2017).

Simulating the crop growth and development using crop models has been increasingly

become valuable for decision support, particularly in climatic risk conditions. Several crop models are being tested and validated for their performance for a given management, variety (ies) and climatic condition. However, their efficiency in simulating the crop response under sequential stresses is not tested enough. One of the reasons for such gap is availability of experimental data itself. In view of the importance of maize and projected increase in climatic variability exposing crop to multiple stresses even in single season at a given location, it is important to simulate the impacts using a crop model so as to improve the decision making on crop management and for developing the adaptation strategies at regional level. In this paper we first quantify the crop response to sequential stresses (excess water and dry spells in a single growing season) and then test the efficacy of an Info Crop-MAIZE model in simulating the crop response under such situations. Info Crop is a decision support system which can simulate the crop growth, development and yield in response to weather, soil, agronomic management (including planting, nitrogen, residues and irrigation), and major pests and diseases (Aggarwal *et al.*, 2006).

Materials and Methods

Experimental site and weather condition

The field experiments was conducted during kharif season of 2010 in the Research Farm of Indian Agricultural Research Institute (latitude 28.4°N and longitude 77.11°E), New Delhi. The soil has a pH of 8.16 and EC of 0.295dS m⁻¹ with a bulk density of 1.41 Mg/m³. Soil texture is sandy loam with soil organic carbon of 0.28% and has the soil available N @ 170 kg ha⁻¹, available P @ 8.88 kg ha⁻¹ and available K @ 207 kg ha⁻¹. The field capacity of experimental field was 15.41% w/w and wilting point was 6.34%

w/w. During the experimental period, monsoon rainfall was about 911 mm. The daily mean sunshine duration was about 4.5 hrs. The mean value of evaporation was around 4.3 mm/day while the mean relative humidity (RH) was 78% during the south west monsoon. The mean maximum temperature was 32.5°C while the mean minimum temperature was 23.6°C.

Treatments

Field experiment was laid out under homogenous condition of field with treatments of flooding and drought alone and in five different combinations at different phases of crop growth viz., Irrigated as and when required (I); Rainfed (RF); Rainfed-Moderate drought-Excess water (RF-D-EW); Moderate drought-Rainfed-Excess water (D-RF-EW); Excess water- Rainfed-Moderate drought (EW-R-D); Moderate drought-Excess water-Rainfed (D-EW-RF); Moderate-drought (MD). Each treatment was replicated three times. Overall, 7 treatments were replicated thrice. In order to attain the initial uniform stand, crop was maintained stress free till 15 DAS. Once crop attained a uniform stand (15 DAS), initial stress was given in each case and this was maintained for about one month (15-50 DAS). There after second stress (50-80 DAS) was given to crops for next 30 days and then the third stress (80-100 DAS) was given, so as to ensure that crop was exposed to different stresses during its growth period in the sequence given earlier.

In case of excess water conditions, the plots were irrigated every morning till flooding was achieved. As the soil was highly porous, continuous standing water for days together could not be strictly achieved. However, the soil moisture was kept to saturation level (25 percent moisture level w/w) and therefore the treatment is designated as excess water treatment.

Crop variety

The maize hybrid HQPM-1 (a cross between HKI 193-1 × HKI 163), suitable for cultivation across the India is a late duration variety with yellow color dent type seed with average yield of about 60 q/ha. This hybrid is resistant to frost/cold and also to common rust.

Sowing of crop and its management

The seeds of maize hybrid HQPM-1 were dibbled along the rows spaced at 60cm apart with plant to plant spacing of 20cm at a depth of 5cm, using 20 kg seeds/ha. Sowing was done on 10 July, 2010. All plots received phosphorus @60 P₂O₅ kg ha⁻¹ through SSP, potassium @60 kg ha⁻¹ through MOP at the time of sowing. Nitrogen @ 120kg ha⁻¹ was applied in the form of urea in three equal split doses viz., 1/3 as basal, 1/3 at knee high stage and 1/3 at tasseling stage. Atrazine at 1.0 kg ha⁻¹ was applied two days after sowing as pre-emergence to control the initial flushes of weeds. In addition to this two time manual weeding was done at 45 DAS and 85 DAS. Soil moisture in different treatments at the beginning of each stress was estimated using gravimetric method. The moisture status of soil varied from 8.36% to 25.43% in various treatments at different crop growth stages. Prior to the first stress, soil moisture was 13.72% and varied significantly during the course of crop growth due to variation in treatments.

Sampling and observations

Observations on phenology (Days to 50% germination, 50% silking and 50% physiological maturity) were taken on plants in different treatments. Observations on yield and yield components were also taken at the harvest. Mature cobs and stover were harvested manually from one square meter

area and sun dried for few days. Then the dried cobs were dehusked and shelled manually and grain yield was recorded at 15% moisture content and expressed in kg ha⁻¹. The number of rows and number of grains or kernels per cob were counted from five randomly selected cobs in each plot. Shelling percentage (%) and harvest index (HI) were calculated using:

$$\text{Shelling percentage (\%)} = \frac{\text{Grain weight (kg ha}^{-1}\text{)}}{\text{Cob weight (kg ha}^{-1}\text{)}} \times 100$$

$$\text{Harvest index} = \frac{\text{Grain yield (kg ha}^{-1}\text{)}}{\text{Grain+stover yield (kg ha}^{-1}\text{)}} \times 100$$

Statistical analysis

The data on phenology, yield variables and grain yield of maize were analyzed by applying the technique of ‘analysis of variance (ANOVA)’ for Randomized Block Design using SPSS 16.0 software. Critical difference (CD) was calculated at 5% level of significance for comparing the treatment means. CD values have been indicated, where the differences are significant.

Calibration and validation of info crop-maize model

In order to test the model performance in simulating the response of crop to multiple stresses, Info crop model was used. The simulated values on phenology (days to 50% flowering, grain filling duration), total dry matter (TDM) and grain yield (GY) were compared with those of observed values. The observed data set on both irrigated and rainfed plants from the field experiment were used for the calibration and fine tuning of the model.

Initially, the model was calibrated for varietal performance using the varietal characteristics for irrigated conditions. For attaining the proper phenology, total dry matter and yield,

several iterations were done and simulations runs were made. After satisfactory performance of model in irrigated conditions, the simulations were done for rainfed conditions and calibration was repeated through less iteration so as to get proper simulation results in rainfed conditions as well. To simulate the multiple stresses, conditions were imposed and tested the model performance. The calibrated model then was used to simulate the response of maize crop to multiple stresses in a crop growth period. The remaining five treatments viz. MD; RF-D-EW; D-RF-EW; EW-RF-D and D-EW-RF in maize crop was used for the simulation purpose.

Evaluation of model performance

Three statistical measures and indices were applied to evaluate the model that included mean bias error (MBE) (Addiscott and Whitmore 1987), root mean square error (RMSE) (Fox 1981) and modeling efficiency (ME) (Nash and Sutcliffe 1970).

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

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

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

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 error as it accounts for positive and negative deviations. 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 deviation between simulated and observed state variables with the variances of observed values of development, growth and yield.

Results and Discussion

Crop phenology

The days to 50 % germination not affected significantly as the initial condition up to 15 DAS was similar in all the treatments. While, days to 50% silking and 50% physiological maturity was affected significantly due to effect of moisture related sequential stresses with the highest value observed at irrigation condition viz. 63 and 107 respectively (Table 1). Lowest values of 50% silking and 50% physiological maturity were recorded at moderate drought condition.

Under adequate irrigation regime, silking delayed by about one week as compared to that of rainfed crop, while the moderate drought advanced silking by 10 days as compared to that of adequately irrigated crop (Table 1). Coincidence of vegetative period with moderate drought advanced silking while with excess water it delayed.

Yield parameters

The yield attributes of maize such as number of rows per cob, number of grains per cob, shelling percentage (Table 2) and harvest index (Table 3) differed significantly (CD $p=0.05$) due to sequential stresses related to flood and draught with the highest values observed at irrigated condition and lowest values under moderate draught condition. Numbers of grain rows were same under RF and EW-RF-D, while it was also same in RF-D-EW and D-RF-EW treatments. Excess

water during grain filling period also led to reduced number of grains per cob. The highest value of the shelling percentage was recorded under irrigated condition followed by the EW-RF-D, while the lowest value was recorded under the moderate drought condition. Same value of shelling percentage was recorded under RF and RF-D-EW treatments. Same value of harvest index was recorded in D-RF-EW and EW-RF-D treatments (Table 3). There was no significant effect of these stresses on 100 grain weight (Table 2).

Grain yield and total biomass yield

The grain yield, cob weight and total biomass were significantly affected by multiple stresses related to climate change (Table 3). The grain yield was highest in the irrigated condition, while lowest value was recorded under the moderate condition. Grain yield was almost similar in rainfed grown crop or in crop subjected to EW-RF-D conditions. Occurrence of drought during vegetative growth period or during flowering caused more reduction in grain yield. With imposition of stresses RF-D-EW, D-RF-EW, EW-RF-D, D-EW-RF and MD resulted in 46.7%, 51.7%, 35%, 40% and 63.3% decreased in grain yield respectively over irrigated condition. Highest value of total biomass was recorded under the irrigated condition, while the lowest value was recorded in the (D-RF-EW) which was at par with MD (Table 3). The total biomass was decreased with RF-D-EW, D-RF-EW, EW-RF-D, D-EW-RF and MD by 34.7%, 38.3%, 14.9%, 29.1% and 36.9% respectively.

Calibration of info crop-maize model

The model parameters and interpolation functions were calibrated for maize hybrid (HQPM-1) from the field experiment data set.

Table.1 Effect of moisture related sequential stresses on phenology and leaf area index of maize crop in monsoon season

Initial condition (up to 15 DAS)	Treatment	Phenology (Days from sowing)		
		50% Germination	50% Silking	50% Physiological maturity
RF	I	6	63	107
RF	RF	7	56	97
RF	RF-D-EW	6	58	101
RF	D-RF-EW	6	54	102
RF	EW-RF-D	6	65	105
RF	D-EW-RF	7	58	101
RF	MD	6	53	94
	CD p=0.05	NS	1.44	1.72

I=Irrigated as and when required; RF=Rainfed; RF-D-EW=Rainfed-moderate drought-excess water; D-RF-EW=Moderate drought-rainfed-excess water; EW-RF-D=Excess water-rainfed- moderate drought; D-EW-RF=moderate drought-excess water-rainfed; MD=Moderate-drought

Table.2 Effect of moisture related sequential stresses on yield components of maize crop

Initial condition (up to 15 DAS)	Treatment	Rows cob ⁻¹ (No)	Grain cob ⁻¹ (No)	100 grain weight (g)	Shelling %
RF	I	13	285	26.7	77
RF	RF	12	221	25.3	72
RF	RF-D-EW	11	158	24.8	72
RF	D-RF-EW	11	171	25.5	73
RF	EW-RF-D	12	219	25.8	76
RF	D-EW-RF	10	155	25.1	74
RF	MD	9	92	24.1	66
	CD p=0.05	1.65	53.18	NS	3.62

*For treatment details refer the foot note of table 1

Table.3 Effect of moisture related sequential stresses on grain yield, cob weight and total biomass yield (kg ha⁻¹) of maize crop

Initial condition (up to 15 DAS)	Treatment	Grain yield	Cob weight	Total biomass	Harvest index
RF	I	5000	6493	11750	43
RF	RF	3250	4530	9583	34
RF	RF-D-EW	2667	3726	7667	35
RF	D-RF-EW	2417	3325	7250	33
RF	EW-RF-D	3250	4271	10000	33
RF	D-EW-RF	3000	4032	8333	36
RF	MD	1833	2797	7417	25
	CD p=0.05	375	446	627	6.22

*For treatment details refer the foot note of table 1

Table.4 Observed and simulated value of the calibration of Info Crop-Maize model

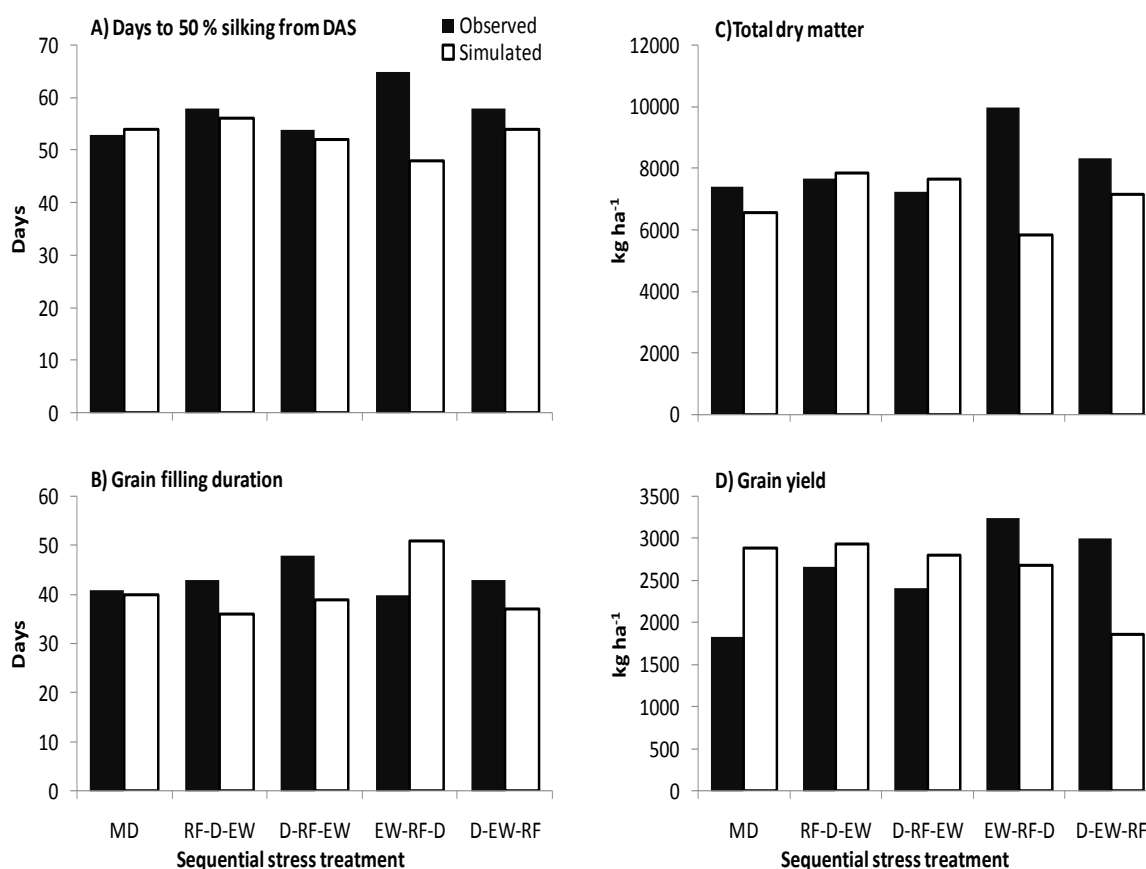
Parameters	Irrigated		Rainfed	
	Observed	Simulated	Observed	Simulated
Days to 50% silking (from DAS)	63	62	56	56
Grain filling duration (days)	44	45	41	44
Total dry matter (kg. ha ⁻¹)	11750	12872	9583	10551
Grain yield (kg. ha ⁻¹)	5000	5161	3250	3831

Table.5 Statistical indices showed performance of Info Crop-Maize model

Parameters	MBE	RMSE	ME
Days to 50% silking (from DAS)	-4.80	7.92	-2.52
Grain filling duration (days)	-2.40	7.59	-6.58
Total dry matter (kg. ha ⁻¹)	-1122.00	1985.00	-2.91
Grain yield (kg. ha ⁻¹)	-2.20	769.00	-1.46

MBE=Mean bias error; RMSE=Root mean square error; ME=Modeling efficiency

Fig.1 Validation results on Info Crop-Maize model for simulating the effect of multiple-stresses on ground nut crop on A) days to 50% silking from DAS, B) grain filling duration in days, C) total dry matter (kg. ha⁻¹) and D) grain yield (kg. ha⁻¹)



The simulated phenology (days to 50% silking and grain filling duration) almost matched with that of observed values under the irrigated condition, while the observed and simulated values on grain filling duration was 41 and 44 days respectively and simulated value was slightly higher than the observed one (Table 4). The simulated values of total dry matter and grain yield under irrigated condition and total matter under rainfed condition matched with those of observed ones. Under rainfed condition the simulated and observed values on grain yield was 3250 and 3831 kg ha⁻¹ respectively. All these above parameters showed satisfactory performance of model when compare with the observed values and the deviation was within the acceptable limits of 10%.

Simulating the crop response to multiple stresses

Comparision between observed and simulated values showed that days to 50% silking was simulated well by the model except in EW-RF-D treatment where the simulated value was much lower than the observed value (Fig. 1A). Results showed that the grain filling duration was simulated well only in moderate draught (MD) treatment (Fig. 1B). The simulated value for grain filling duration was 11 days lower than the observed value in D-RF-EW treatment and 11 days higher than the observed value in EW-RF-D treatment. In EW-RF-D condition the simulated value for grain filling duration was much higher than the observed one. Total dry matter was simulated well in RF-D-EW and D-RF-EW conditions (Fig. 1C) where simulated values for total dry matter was 2.4 and 5.4% higher than the observed one. In MD and D-EW-RF conditions the simulated value for total dry matter was lower than the observed one and it was lower by 13.3 and 16.2 % respectively. It was found that in EW-RF-D condition the simulated value for total dry matter is about

half than the observed one. Grain yield was simulated well in treatments RF-D-EW and D-RF-EW only (Fig. 1D) where simulated value was higher by 8.9 and 13.7% respectively. The grain yield was over estimated in moderate draught (MD) condition and the simulated value of the grain yield was 36.6% higher than the observed. Under EW-RF-D and D-EW-RF conditions grain yield was under estimated and the simulated values for grain yield was 21.4 and 61.3% lower than the observed values respectively.

Statistical performance of model

From the data set it was observed that mean bias error (MBE) showed the negative deviation for the days to 50% silking, grain filling duration, total dry matter and grain yield (Table 5). Root mean square error (RMSE) values showed that the accuracy of model was higher for the days to 50% silking and grain filling duration, and it was lower for grain yield and total dry matter. Modeling efficiency also showed that under estimation of model for the crop parameters.

Overall results on phenology, biomass accumulation and distribution, yield and yield components indicate that the maize plants responded differentially to sequential stresses depending on the coincidence of the occurrence of type of stress. The sensitivity of crops and crop parameters also differed with regards to sequential stresses. The variation among crop species for response to droughts or floods is well documented (Liao and Lin, 2001; Prasad *et al.*, 2008). In maize, drought stress caused reduction in vegetative phase, grain filling period and therefore crop growth period. Excess water during grain filling period delayed the crop maturity. The total biomass was most affected in plants exposed to drought stress during the vegetative growth period and then subjected to excess water

during grain filling period. Continuous drought condition caused most reduction in total biomass. Maize has been reported to be very sensitive to drought (Farre *et al.*, 2000) as it leads to reduction in growth, content of chlorophyll pigments (Lima *et al.*, 2002), nutrient uptake, impaired active transport (Tanguilig *et al.*, 1987). Flooding/water logging leading to anaerobiosis causing severe injury and yield loss (Voesenek *et al.*, 2006). Flooding also causes reduction in photosynthetic capacity, root injury, reduced water uptake, (Jackson, 2002 and Yordanova *et al.*, 2005), reduction in fresh and dry weight (Seema *et al.*, 2009) and reduction in leaf number (Ali *et al.*, 1999).

The yield and yield parameters were also influenced by the sequential stresses. Moderate drought condition reduced the cob weight, number of grain rows, number of grain per cob, harvest index and shelling percentage. Excess water during grain filling period also led to reduced number of grains per cob. The grain yield was significantly highest in the irrigated condition, while the lowest value was recorded under the moderate drought condition. Grain yield was almost similar in rainfed grown crop or in crop subjected to EW-RF-D conditions. Occurrence of drought during vegetative growth period or during flowering caused more reduction in grain yield. Even though 100 grain weight was not affected significantly by the occurrence of different stresses, maximum weight of 100 grains was recorded in irrigated condition while the least weight was recorded in moderate drought condition. Same value of harvest index was recorded in D-RF-EW and EW-RF-D treatments and similar values of shelling percentage were recorded under RF and RF-D-EW treatments. Stress just before anthesis and at anthesis caused significant increase in floral abortion and lower seed numbers in maize (Claassen and Shaw, 1970). Post-anthesis moisture deficit on the other hand significantly reduced grain yield (Olaoye *et al.*, 2009). Flooding and submergence caused by heavy rainfall, water logging in poorly drained soil or high water table is one of the most common constraints for maize production

(Zaidi *et al.*, 2005). In maize early seedling stage was found to be highly susceptible, followed by the knee-high stage (Zaidi and Singh 2002; Zaidi *et al.*, 2004) to flooding or excess moisture.

The simulation analysis indicated that the InfoCrop model on maize worked satisfactorily for rainfed and irrigated conditions and could be calibrated for the experimental conditions for these treatments. Maize model simulated days to 50% silking well in all situations of multiple stresses except in case where rainfed crop was exposed to excess water/flooding during flowering and then to terminal drought. Grain filling duration was also simulated well in moderate drought conditions but in other situations it slightly under-estimated the duration except where crop was exposed to terminal drought. As a consequence, the total dry matter and yield also was simulated satisfactorily in most of the cases. The temperature and rainfall intercalational influences were satisfactorily simulated using InfoCrop maize (Byjeh *et al.*, 2010) and sorghum (Srivastava *et al.*, 2010) models. However, there is a need for more refinement from the experimentation and model point of view for carrying out better simulations of situations where maize is exposed to excess water/flooding in vegetative period and then to terminal droughts as also in case of occurrence of droughts during vegetative period and then exposed to excess water/flooding coinciding with flowering and initial grainfilling period.

The results indicated that the impacts of drought and flood on crop growth and yield are multi-dimensional. The sensitivity of crops and crop parameters also differed with regards to sequential stresses. The drought condition hastened the occurrence of crop phenological events in maize and coincidence of drought situation with early growth period hastened flowering, while excess water caused delay in flowering and crop maturity. The total biomass was most affected in plants exposed to drought stress during the vegetative growth period and then subjected to excess water during grain

filling period. Occurrence of drought during vegetative growth period or during flowering caused more reduction in grain yield. The simulation analysis indicated the Info Crop maize model could be satisfactorily calibrated to rainfed and irrigated conditions. The maize model was robust in simulating the effects of sequential multiple stresses except in few events such as when maize is exposed to excess water/flooding in vegetative period and then to terminal droughts as also in case where crop exposed to droughts during vegetative period and then to excess water/flooding coinciding with flowering and initial grainfilling period. Results also indicate that, more experimentation is required to test the performance of models in these situations and also for refining them.

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