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Evaluation of the DSSAT model for maize yield estimate under different irrigation regimes

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ABSTRACT

This study has been designed to evaluate the performance of DSSAT model for yield estimation of maize under different irrigation levels and methods. Experiment has been conducted during *rabi* 2015-16 in water Technology Centre, Rajendranagar. Observed yields were compared with the models simulated yields. From the results it has been revealed that drip irrigation scheduled at 1.0 Epan produced higher growth, yield, and yield attributes than the other surface and drip irrigation treatments, while surface irrigation scheduled at 0.6 IW/CPE produced lower growth, yield, and yield attributes than the other treatments. Model results were also in quite agreement with the observed results where the maximum and minimum prediction errors in grain yields with DSSAT was 0.40 % and 14.86 %. Correlation coefficient of 0.98 and 0.97 was observed for water productivity and grain yield. From this study it can be concluded that DSSAT can be used for yield estimation in maize under different irrigation regimes with minimal error. Model should be used after proper calibration for better results.

Key words: *DSSAT, Irrigation, Surface irrigation, EPan*

Introduction

Water is one of the essential natural resource because of its irreplaceable role in sustaining and functioning of environment and society. Agriculture is considered to be a prominent economy sector where most of the population reside on it. It is extremely reliable on water and gradationally subject to water risk. Climate change has become real which has been predicted to escalate the variations in precipitation, ground water level, melting of snow and glaciers and finally affecting on crop water needs. In the forthcoming years farmers will be facing rise in rivalry from non-agricultural users due to hike in burgeoning population, urbanization and water demands from industrial sector. Other side amelioration in water quality through pollution, salinization, excess use of chemicals in farming and industrial release of toxic and hazardous wastes is increasing prominently while the supply of fresh water is more or less constant. This situations calls for improving agriculture water management for sustainable, productive and profitable food sector. Irrigation will not be sustainable if water supplies are not reliable. Most of the cultivated land in India comes under rainfed which contributes to more than 40% of production (Gumma *et al.*, 2021). Major requirement for development of sustainable irrigation is to increase

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WUE, irrigation Efficiency and proper crop planning depending on water availability. Many policies have been aimed to increase WUE or allocative efficiency with minimal reduction in yield through better management practices.

Crop yields depends on water availability, stage and time of irrigation and percent of moisture present in root zone. Many technologies have been developed to increase water use efficiency and focussing on "more crop per drop". Previous studies reveal that development of decision support tool for increasing water productivity and WUE has been attempted.Understanding and predicting crop growth and development under different climatic scenarios and management practices asserting towards sustainability is highly essential. Agronomic experiments which will provide such information is available but are time consuming, expensive and labour intensive. However these methods are insufficient to meet the agricultural demand and needs for decision making process because these trails are site and season specific and limited to few treatments. With this drawbacks it can be noted that there is an urge to develop a tool which can easily produce outputs under varied climatic and management practices within less period of time and results will be quickly available for end users in decision making. This led to the development of crop models.

Crop models are mathematical expressions which describes the effect of climate, soil, genetics and crop management practices on yields. It opens up window for testing new cultivars, different irrigation methods and levels, fertilizer doses and many other to see effect on yield without conducting trails physically. Past findings reveal that DSSAT (Decision support system for Agro Technology Transfer) model has been used in many countries over the world wide under wide range of applications (Hoogenboom *et al.,* 2010), climatic variations (Rasse *et al.*, 2000) and irrigation management (Kadiyala *et al.,* 2015). DSSAT can be used to simulate 42 crops which used climate, soil crop and management details for yield prediction. CERES rice and maize has been used under different locations (Liu *et al.,* 2011; He *et al.*, 2012; Salmeron *et al.*, 2012 and Jeong *et al.*, 2014) with good agreements between observed and simulated results. Meagre studies have been done on the effect of different irrigation methods and levels on maize growth and development using crop models in semi-arid climate of Telangana state. Hence with this background this study has been designed with the following objectives.

1. Evaluating the effect of irrigation methods and levels on yield and yield attributes using DSSAT model.
2. Comparing the model results with observed field values by using statistical analysis.

Materials and Methods

Experimental site

The experiment was carried out during *rabi* 2015-16 in water Technology Centre, Rajendranagar where semi-arid tropical climate ($17^0$19′25.2′′N, $78^0$24′31''E and 534 m above sea mean level) exists. The site's soil was sandy clay loam (52.2 %, 23.7%, 24.1% sand, silt and clay) and slightly alkaline reaction (pH 8.0) with low in organic carbon (0.40%) and nitrogen (100 kg ha^{-1}), medium in phosphorous (33kg ha^{-1}) and potassium (392.44 kg ha^{-1}).

Treatment details

Sowing of the crop was done on 05-10-2022 with harvesting in first week of February. The experiment was discussed in detail by Roja *et al.,* (2020). Briefly the design of the experiment was Randomized block design with surface and drip irrigation treatment combinations. The treatments consists of four surface and four drip irrigation levels. The treatments are as follows surface irrigation at 0.6 IW/CPE ratio (T_1), 0.8 IW/CPE ratio (T_2), 1.0 IW/CPE ratio (T_3), 1.2 IW/CPE ratio ($_{T4}$) , drip irrigation at 0.6 Epan (T_5), 0.8 Epan (T_6), 1.0 Epan (T_7), and 1.2 Epan (T_8). Deklab super 900 M was selected for this study. Recommended fertilizer dose was 200kg N, 80 kg P_2O_5 and 80 kg K_2O. Irrigation was scheduled at alternate days in case of drip irrigation (T_4 to T_8) where as in surface irrigation IW/CPE ratio (T_1 to T_4) is followed. Depth of 50mm irrigation water is followed and irrigation was rescheduled whenever cumulative pan evaporation (CPE) to 83.3 mm, 62.5 mm, 50 mm and 42 mm in T_1, T_2, T_3 and T_4 treatments, respectively.

Measurements

Irrigation is being scheduled based on pan evaporation and the meteorological details like maximum temperature, minimum temperature, pan evaporation, solar radiation and relative humidity were collected from Agricultural Research Institute, Rajendranagar. For model data was collected from

Indian Meteorological Department (IMD) during the crop growth period. Solar radiation was calculated through Hargreaves method. For DSSAT weather man module is used for setting climate data. Soil data required for the model were collected from field analysis and ISRIC (*International Soil Reference and Information Centre). Genotypic characters of cultivars were collected from the past studies. All the required management practices were fed in to the model.* Date of emergence, days to 50% flowering, water use, water productivity, grain yield, test weight, grain N at maturity, harvest index, physiological maturity and statistical analysis were compared between observed and DSSAT model.

DSSAT

DSSAT(Decision support system for Agro Technology transfer) which was developed by university of Florida which can simulate daily outputs like grain and biomass yield, water use and water productivity etc., asfor more than 42 crops (Hoogenboon *et al*., 2010) under varied management practices. Soil, climate, crop and management practices are the minimum data sets required for this model. In this study CERES maize module has been used for simulating different parameters which is capable of simulating effects of cultivar, time of sowing, weather , irrigation and nutrient levels etc., on maize growth and yield. Model combines mathematical equations to describe basic flow and conversion procedure of soil C, water and nutrient balance on daily basis and it can forecast changes in water use, crop growth, yield and nutrient uptake on daily basis.

Statistics

Performance of the model was evaluated using different statistical formulae. Goodness of fit between observed and simulated values were finded out using prediction error. The Co-efficient of determination (R^2) and model efficiency (E) were used to access the predictive power of the model while prediction error mean (P_e), absolute error (MAE) and root mean square error (RMSE) indicated the error in the model prediction. The computed RMSE values determine the degree of agreement between the simulated and observed values, and a low RMSE value close to one was preferred. Statistical formulae used for evaluation are listed below:

$$R^2 = \left[\frac{\left(\Sigma(O_i-\bar{O})(S_i-\bar{S})\right)}{\sqrt{\Sigma(O_i-\bar{O})^2\,\Sigma(S_i-\bar{S})^2}}\right]^2 \qquad 2.6.1$$

$$P_e = \frac{(Si - Oi)}{Oi} \times 100 \qquad 2.62$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(O_i - S_i)^2} \qquad 2.63$$

$$MAE = \sqrt{\sum_{i=1}^{N}\frac{(Si - Oi)}{N}} \qquad 2.64$$

Where,
n = No. of observations
O_i = Observed value
S*i* = Simulated value

Results and Discussion

Days to 50 % flowering and Days to maturity

Observed days to 50% flowering ranges from 54-56 days after sowing while DSSAT model range was from 50-53 days from sowing. DSSAT model predicted values for days to maturity was in agreement with observed values with one or two days deviation which is acceptable. This deviation might be due to model has not considered the real time observations in field like stress or any other abiotic stress (Table 1).

Grain yield

The drip irrigation with 1.0 Epan (5.13 tha^{-1}) produced the highest grain production, which was substantially different from the rest of the treatments except drip at 1.2 Epan (4.92 tha^{-1}). This could be attributed to adequate soil moisture in the root zone depth throughout the crop growth cycle, allowing for improved water and nutrient uptake while also favouring increased production and transfer of photosynthates to the sink via high dry matter production and yield contributing parameters such as number of cobs per plant, shelling percentage, cob weight, grain weight, and test weight. Surface irrigation produced the lowest grain production (2711 kg ha^{-1}) when the IW/CPE ratio was 0.6 (a significant difference from all other treatments). Similar findings were reported by Tariq *et al.*,(2009), Ramah *et al*. (2009) and Hamidreza *et al*. (2011). DSSAT model also resulted highest grain yield in drip at 1.0 Epan (4.83 tha^{-1} and 4.92 tha^{-1}). Drip Irrigation at 1.2 Epan also resulted maximum yield (4.92 tha^{-1}) because model has not considered excess amount of irrigation water. Incase of DSSAT model zero prediction error (0.0 %) was seen under 1.2 IW/CPE ratio, while maximum prediction error of 14.76 % was seen under 0.6 IW/CPE ratio.

Water productivity

Results from the experiment revealed that maximum water (5670 mm) has been used under surface irrigation at 1.2 IW/CPE, while the lowest (3130 mm) has been seen under 0.6 Epan which was on par with 0.6 IW/CPE ratio. Lower water productivity (7.71 kg $ha^{-1}mm^{-1}$) was observed among surface irrigation at 1.2 IW/CPE ratios. Where as in case of DSSAT model minimum (1.88) and maximum (14.40) prediction errors were seen in surface irrigation at 1.2 IW/CPE ratio and 0.6 IW/CPE ratio. There was no much significant difference observed between observed and DSSAT model water productivity. The average WP of observed and simulated were 9.70 and 11.21 (kg ha^{-1} mm^{-1}). Model prediction error was less in case of drip irrigation compared to surface irrigation. Low leaf water content and high leaf water potential in the crop, as well as a considerable decline in grain and fodder yields as a result of moisture stress during the crop's development cycle, might all be contributing factors to lower water productivity. Similar results were reported by Parthasarathi *et al*. (2013) and Manal *et al*. (2007) in maize crop. Reason for deviation in prediction error for water productivity was due to model has irrigated more amount than the required irrigation.

Statistical Analysis

Statistical analysis have been calculated for days to maturity, water productivity and grain yield with Aquacrop and DSSAT models. In case of DSSAT model correlation coefficient was 0.70, 0.98 and 0.97, RMSE was 1.41, 0.32 and 0.14 and MAE was 113, 10.09 and 4.29.

Conclusion

DSSAT crop model are used as a tool for estimation

Table 3. Statistical data for different parameters using DSSAT model

Category	Correlation	RMSE	MAE
Days to maturity	0.70	1.41	113
Water productivity	0.98	0.32	10.09
Grain yield	0.97	0.14	4.29

Table 4. Observed and simulated days to 50 % of flowering, days to maturity and grain yields under DSSAT model

Treatment	Observed			DSSAT			Prediction error
	Days to 50% flowering	Days to maturity	Grain Yield t ha^{-1}	Days to 50% flowering	Days to maturity	Grain Yield t ha^{-1}	
0.6 IW/CPE	54	115	2.71	50	111	3.11	14.76
0.8 IW/CPE	55	116	3.36	53	114	3.63	8.03
1.0 IW/CPE	55	116	3.95	53	115	4.34	9.87
1.2 IW/CPE	56	117	4.37	51	112	4.37	0.00
0.6 Epan	54	115	4.11	51	111	4.40	7.05
0.8 Epan	55	116	4.44	51	113	4.69	5.63
1.0 Epan	56	118	5.13	51	115	4.92	4.09
1.2 Epan	56	118	4.94	51	115	4.92	0.40

Table 2. Observed and simulated total water used and water productivity under DSSAT model

Treatment	Observed		DSSAT simulated		Pe
	Total water used (mm)	WP ($kgha^{-1}mm^{-1}$)	Total water used (mm)	WP ($kgha^{-1}mm^{-1}$)	
0.6 IW/CPE	3170	8.55	3180	9.78	14.40
0.8 IW/CPE	3670	9.16	3680	9.86	7.74
1.0 IW/CPE	4670	8.46	4680	9.27	9.64
1.2 IW/CPE	5670	7.71	5680	7.69	0.18
0.6 Epan	3130	13.13	3220	13.66	4.06
0.8 Epan	3954	11.23	4000	11.73	4.42
1.0 Epan	4775	10.74	4880	10.08	6.16
1.2 Epan	5596	8.83	5680	8.66	1.88

grain yield and water productivity etc., of maize under different irrigation methods and levels in semi-arid tropical climate. This experiment clearly demonstrated that, with the same amount of irrigation water in both the surface and drip treatments, exception of drip irrigation at 1.2 Epan, drip irrigation at 1.0 Epan resulted in greater growth, yield, and other qualities when compared to other surface and drip irrigation treatments. Surface irrigation at 0.6 IW/CPE resulted in decreased growth, yield, and yield characteristics compared to the other treatments. In case of DSSAT model highest was recorded in case of drip at 1.0 Epan and this can be due to high availability of moisture in root zone throughout the crop growth and lowest in case of surface irrigation at 0.6 IW/ CPE ratio, Which can be due to application of irrigation water in less amounts at a time which is not available to the plants. In case of grain yield highest correlation has been seen with DSSAT model 0.97 which concludes that this model can be used effectively for estimating maize yields under different irrigation levels and methods. RMSE values of 0.14 were observed with DSSAT. Deviation in models yields compared to observed might be due to model is not taking in to consideration regarding effect of weeds, pests and diseases on growth and yield of crop which will affect the model predictions to some extent.

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