British Journal of Environment & Climate Change

7(2): 83-91, 2017; Article no.BJECC.2017.007
ISSN: 2231–4784

Soil Water and Nitrogen Balance Study of Maize Using CERES Maize Model in DSSAT

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Authors' contributions

This work was carried out in collaboration between all authors. Authors GS, BAL and KNS designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors SQ, PS, ZAD and SK managed the analyses of the study. Author AF managed the literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/BJECC/2017/31732

Original Research Article

Received 2nd January 2017
Accepted 9th March 2017
Published 3rd July 2017

ABSTRACT

Simulated studies indicated that early sowing i.e 15th April (D_1) predicted highest grain yield during all the years from 1986-2013. Under irrigated conditions increasing levels of N predicted increased grain and stover yield from N levels up to 90 kg N ha^{-1}. Under irrigated and mulched conditions increased level of N predicted increase in maize grain and stover yield upto 120 kg N ha^{-1}. Whereas under un-irrigated mulched conditions highest grain and stover yield was predicted at 60 kg N ha^{-1}. Maize yield was also simulated at different sowing dates and in combination with variable spacings and it was predicted that under irrigated condition closer spacing 40 cm × 20 cm at 15th April sowing recorded highest grain and stover yield of maize. Under un-irrigated mulched conditions highest grain yield was predicted at 30th April sowing with spacing 65 cm × 20 cm. Soil water balance under simulation studies indicated that potential ET was recorded comparatively higher with early sowing date than late sowing date under both irrigated un-irrigated mulched conditions. Similar trend was recorded with respect to transpiration under both irrigated and un-irrigated mulched conditions. Simulated soil evaporation was more in wider spacing than closer spacing. Similar trend was recorded with regard to simulated run-off. Predicted nitrate content (final) of irrigated soil decreased where under un-irrigated mulched conditions 15th April (D_1) sowing predicted lowest NO_3 leaching than later sowing dates. Under un-irrigated mulched conditions leached nitrate was nominal. Nitrogen denitrification was comparatively more under un-irrigated mulched conditions than irrigated condition. It is concluded that DSSAT v 4.5CERES-

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Maize model is very robust in predicting the growth and yield of maize as influenced by agrotechniques and could be used in wider perspective.

Keywords: DSSAT; ET; run off; N dynamics; simulation.

1. INTRODUCTION

Maize is widely cultivated throughout the world, and produced each year greater than any other grain. The United States produces 40% of the world's harvest; other top producing countries include China, Brazil, Mexico, Indonesia, India, France and Argentina. The maize is cultivated on an area of 161.82 million ha in world with production of 844.36 million tonnes [1]. Maize known as the "Queen of Cereals" is the third most important cereal crop in India after rice and wheat and is cultivated on 8.17 million ha with the production of 19.73 million tonnes and productivity of 4.21 tonnes ha^{-1} [2]. Among the major crops of Jammu and Kashmir in terms of acreage maize is grown in area of 315.81 thousand hectares with the production of 0.63 million tonnes and productivity of 2.0 tonnes ha^{-1} [3]. This increase in yield has been mainly achieved by increase in the area under high yielding varieties. However, the genetic potential of the improved varieties is at least three times of the present average yield of the state. Sowing dates have a pronounced effect on the yield of maize. Maize is generally sown from mid week of April to last week of May in lower belts of valley. However, the field may not be vacant at this appropriate time due to delay in harvesting of some rabi crops. Late sowing results in a significant decline in maize production [4].

The process based dynamic simulation crop models based on soil, crop and weather factors could be effective research tools for planning alternative strategies for crop management, land use and water management [5] and also a useful tool for planning and developing technological interventions in diverse areas. For research planning a validated model with known genetic constants for varieties can be powerful tool for studying the performance of varieties in constrating environments, soil types, diverse cultural practices and management inputs [6]. Technological packages including optimum planting time, irrigation, plant population, suitable varieties and plant geometry can be designed using models. Though this approach has been successfully used in some parts of our country for management decisions and technology evaluation but no efforts have been made in this region. The DSSAT v 4.5 CERES-Maize Crop Simulation Model which was tested over a wide range of environments [7,8] has been used in present investigation to study "Soil water and Nitrogen balance study of maize Using CERES maize model in DSSAT".

2. MATERIALS AND METHODS

The investigation was conducted at the experimental farm of Division of Agronomy at main Campus of Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Shalimar Srinagar which is situated 16 Km away from city center that lies between 34.08° N latitude and 74.83° E longitude at an altitude of 1587 meters above the mean sea level. The experiment included four dates of sowing with three levels of spacing in Sub plot and dates and density in the main plot was laid out in a Split Plot Design with three replications.

The climate is temperate type characterized by hot summers and severe winters. The average annual precipitation over past twenty five years is 786 mm (Division of Agronomy, SKUAST-Kashmir) and more than 80% of precipitation is received from western disturbances during winter/spring months. During crop growth period (15^{th} April - 4^{th} October) the maximum temperature ranged between 18°C to 32°C, while minimum temperature ranged between 4.30°C to 17.78°C with relative humidity 49-89% (maximum) and minimum being between 23% to 86%. The mean monthly meteorological data collected for the cropping season of 2012 and 2013 during experimental period recorded at the Meteorological observatory at Division of Agronomy, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir.

Urea, Diammonium phosphate, Muriate of potash and zinc sulphate were used as source of nitrogen, phosphorus, potassium, and zinc. A fertilizer dose of 10 ton FYM ha^{-1}, 120 kg N ha^{-1}, 60 kg P_2O_5 ha^{-1}, 30 kg K_2O ha^{-1}, 20 kg $ZnSO_4$ ha^{-1} was applied. A fertilizer dose of 10 ton FYM ha^{-1}, 90 kg N ha^{-1}, 60 kg P_2O_5 ha^{-1}, 30 kg K_2O ha^{-1}, 10 kg $ZnSO_4$ ha^{-1} was applied. Decomposed farmyard manure (FYM) was applied after field layout was planned and mixed thoroughly with the soil. Dose of the nitrogen was applied as per the schedule given in 3.7.2.1 and 3.7.2.2. Half of recommended nitrogen was applied as basal dose and rest of nitrogen in two splits. 1st split at knee high stage and 2nd at tasseling stage. Phosphorus, potassium and zinc sulphate was applied, as per the recommendation as basal dose at the time of sowing. Furrow method of irrigations was followed. Irrigation was applied at IW/CPE ratio 0.75 in experiment-I. In IW:CPE approach, cumulative pan evaporation values from standard USWB class 'A' pan evaporimeter were used for scheduling of irrigation. A common depth of irrigation was maintained at 6 cm uniformly [9]. Mulching of the un-irrigated crop was done with the available rice straw. A thin layer of mulch of about 5-10 cm was done.

The soil water balance model of DSSAT is one-dimensional model and computes the daily changes in soil water content by soil layer due to infiltration of rainfall and irrigation, vertical drainages, unsaturated flow, soil evaporation and root water uptake process [10]. The soil has parameters that describes its surface conditions and layer–by-layer soil water holding and conductivity characteristics. The model use a "tipping bucket" approach for computing soil water drainage when a layer water content is above a drained upper limit parameter. The SCS method is used to partition rainfall into runoff and infiltration, based on a "curve number" that was developed by (soil conservation service) used in the model accounts for layered soils and soil water contents at the time when rainfall occurs. When irrigation is applied, the amount applied is added to the amount of rainfall for the day to compute infiltration and run-off.

In the DSSAT flow chart (Fig. 1) 4.5 N sub model the major processes simulated are mineralization and immobilization (influenced by soil temperature, soil water, C/N ratio), infiltration (influenced by soil temperature, soil pH, NH_4 Concentration), denitrification (influenced by soil temperature, soil water pH, soil concentration and NO_3 concentration) and crop uptake (influenced by soil water, inorganic N, crop demand, root length density) [11]. The soil profile is characterised by its initial organic matter and N layers are based on water-holding properties and texture. Transport of N through the soil to lower layers is based on water movement obtained from the soil water balance model [12].

3. RESULTS AND DISCUSSION

To know the role of simulation model in agronomic research, the Decision Support System for Agro-technology Transfer (DSSAT) v 4.5 CERES-Maize model was used. All its functions are fully supported in Windows 95, Windows 98, Windows NT and OS/2 operating systems [13]. This model was used to simulate the growth, development and yield of maize as influenced by planting dates and plant density for the experiments conducted during the cropping seasons of 2012 and 2013. For simulation of CERES-Maize model, minimum data sets (MDS) on crop management, macro and micro-environmental parameters associated with weather, soil and crop are required as input. Input data files of CERES-Maize model are as per IBSNAT standard input/output formats and file structure described in DSSAT v 3 [7].

Model was used to simulate growth and yield of maize under different management strategies. Crop response to varied planting density from 40 cm to 80 cm was simulated using weather data of year 2010, 2011, 2012, 2013. Also Nitrogen levels (N_0, N_{30}, N_{60}, N_{90}, N_{120} and N_{150}) levels were simulated for response of maize crop variety C6. Using CERS maize model in DSSAT V4.5.

Predicted potential ET was higher under irrigated condition than under un-irrigated mulched conditions. Simulated potential ET under irrigated condition ranged from 536 mm to 675 mm and corresponding value for un-irrigated mulched condition was 432.8 to 515 mm. Potential ET was recorded comparatively higher with early sowing dates than late sowing under both irrigated and un-irrigated conditions. Closer plant spacing recorded more Potential ET than wide spacing. Simulated transpiration under both irrigated as well as un-irrigated mulched conditions trend was similar like potential ET with respect to sowing date and spacing of maize crop. Simulated soil evaporation ranged from 207.2 mm to 332.5 mm under irrigated condition where under un-irrigated mulched condition, soil evaporation value ranged from 7.78 to 12.55 mm. Soil evaporation was less under earlier dates of sowing and increased with later sowing dates. Wider spacing predicted more soil evaporation than closer spacing.

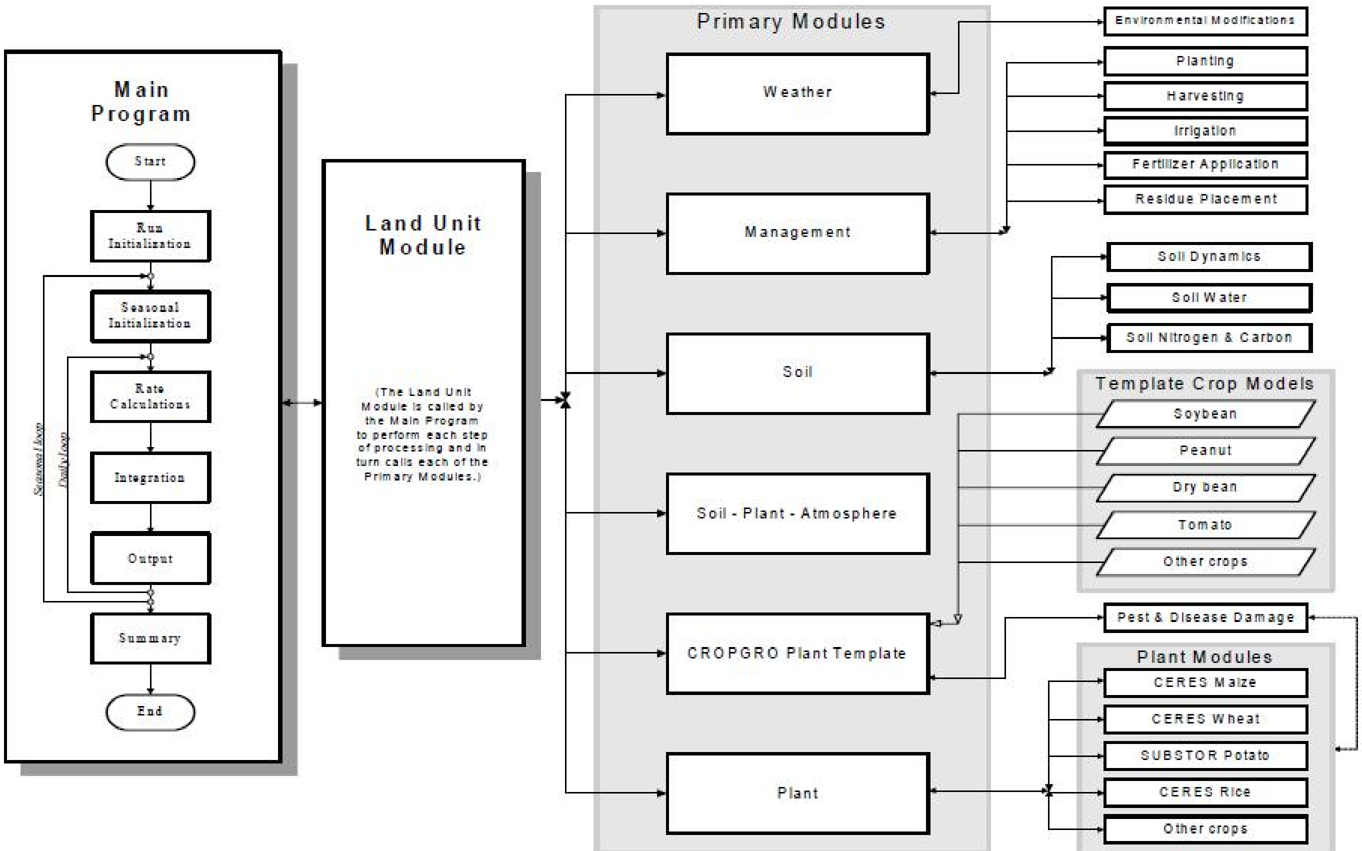

Fig. 1. Overview of the components and modular structure of DSSAT-CSM

Table 1. Simulated soil nitrogen balance

S. no		Irrigated					Un-irrigated mulched				
		15th April	30th April	15th May	30th May	Mean	15th April	30th April	15th May	30th May	Mean
A.	NO_3										
	Initial	166.95	166.95	166.95	166.95	**166.9**	166.95	166.95	166.95	166.95	**166.9**
	Final	84.80	86.98	73.71	64.87	**57.6**	170.98	175.32	179.83	179.51	**176.4**
B.	NH_4										
	Initial	17.89	17.89	17.89	17.89	**17.9**	17.89	17.89	17.89	17.89	**17.9**
	Final	2.71	2.83	3.07	3.08	**2.92**	1.11	1.28	1.09	1.67	**1.28**
C.	Fertilizer N										
	Initial	89.00	89.00	89.00	89.00	**89.00**	89.00	89.00	89.00	89.00	**89.00**
	Final	--	--	--	--	**--**	--	--	--	--	**--**
E.	Leached NO_3										
	Initial	--	--	--	--	**--**	--	--	--	--	**--**
	Final	88.57	97.20	119.23	127.94	**108.23**	0.00	0.44	1.79	2.18	**1.47**
F.	N denitrified										
	Initial	--	--	--	--	**--**	--	--	--	--	**--**
	Final	0.71	0.69	0.67	0.64	**0.67**	4.48	4.78	1.79	5.77	**4.20**
G.	N uptake from soil										
	Initial	--	--	--	--	**--**	--	--	--	--	**--**
	Final	139.58	129.99	124.87	129.19	**130.8**	128.80	126.22	124.61	129.90	**127.3**

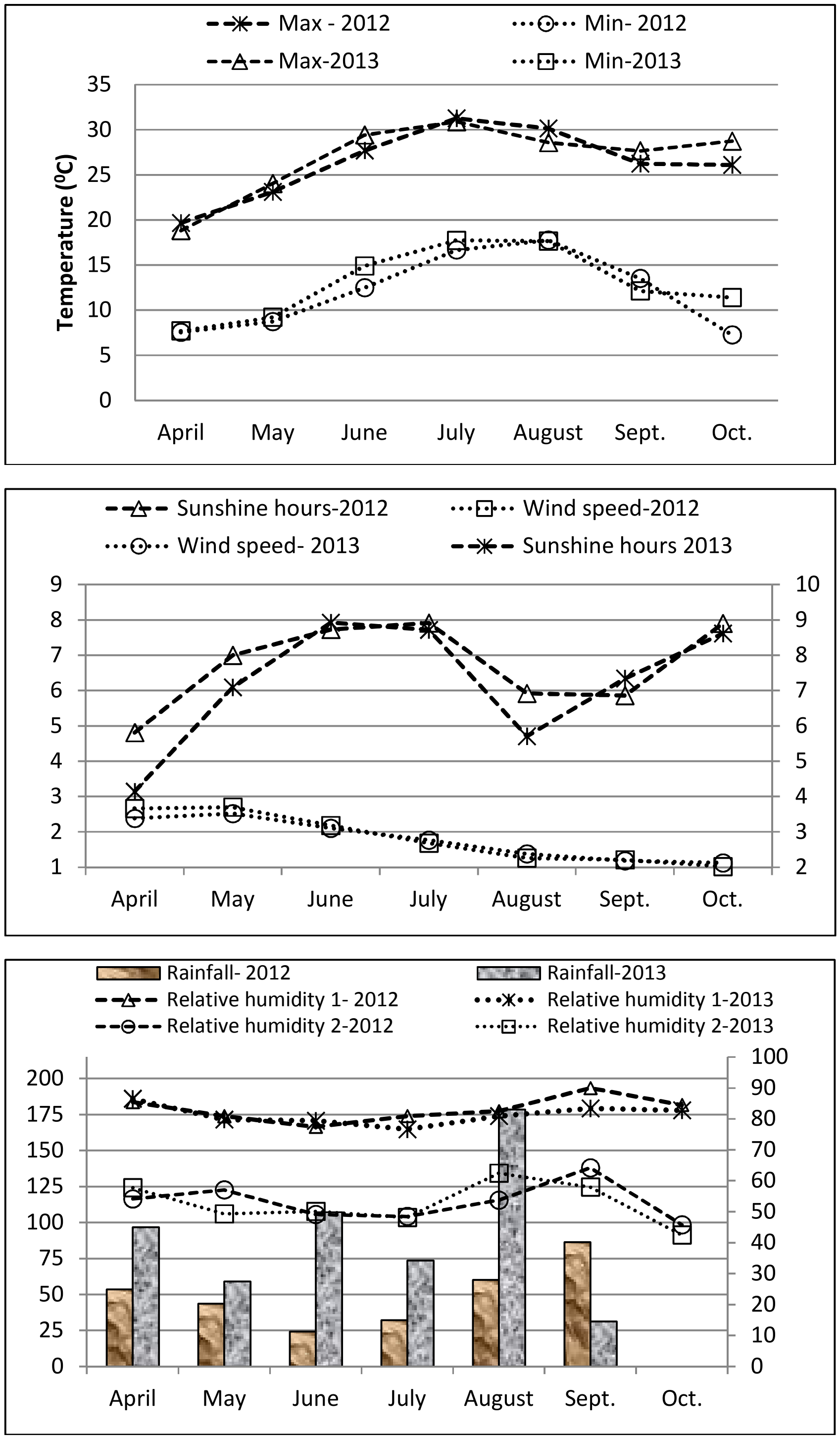

Fig. 2. Temporal change in weather parameters during field experimentation

Simulated run-off was not influenced by sowing date. Though run-off value was more under irrigated condition as compared to un-irrigated mulched conditions of maize crop. Wider spacing of maize predicted more run-off than closer spacing. Predicted potential ET was higher under irrigated condition than under un-irrigated mulched conditions. Potential ET ranges from 536.5 to 675 mm. Where under un-irrigated mulched conditions potential ET ranges from

423.5 to 515 mm. Due to less availability of water under un-irrigated mulched condition ET is expected to be low. Similarly early sowing dates recorded more ET than late sowing date because growth period of early sowing date was recorded more than late sowing dates. Similar findings were reported by [8]. Similar trend was recorded with regard to transpiration. Under irrigated conditions transpiration ranges from 211.3 to 251.6 mm. Where under un-irrigated mulched conditions transpiration ranges from 196.2 to 228.1 mm.

Predicted soil evaporation ranges from 207.2 to 332.5 mm under irrigated conditions. Where under un-irrigated mulched condition the soil evaporation was exceedingly low ranges from 7.78 to 12.55 mm. Results indicate that lot of moisture can be saved by the use of mulch. The result are in conformity with the findings of [14]. Consequent upon use of mulch lowest run-off was predicted under un-irrigated mulched condition as compared to irrigated conditions. Run-off under irrigated condition ranges from 28.03 to 73.72 mm. Where

Fig. 3. Simulated potential ET, Run-off, Soil evaporation and Transpiration as influenced by planting dates with density under both irrigated and unirrigated conditions

under un-irrigated mulched condition run-off ranges from 0 to 4.64 mm. Similar observations were reported by [15].

Nitrate content under irrigated condition decreased at all sowing dates. Where under un-irrigated mulched condition there was marginal increase in nitrate content. This can be attributed to the reason that under irrigated condition run-off was high, soil evaporation was high as compared to un-irrigated mulched conditions. Where nitrate losses might have been less. Similar observations were reported by [16]. Ammonical nitrogen was predicted under both conditions (irrigated and un-irrigated) decreased by 83.6 and 92% from initial to final and this can be attributed to utilize uptake of ammonium nitrogen by plant.

As expected nitrate leaching was more under irrigated condition and very low under un-irrigated mulched conditions. Similar findings were reported by [17]. Denitrification was comparatively higher under un-irrigated mulched condition. Total N uptake from soil was not affected by irrigated and un-irrigated mulched conditions. Where under irrigated condition early dates of sowing predicted more uptake than late date of sowing. This can be attributed to more utilization of resources at early date of sowing due to longer growth duration.

4. CONCLUSION

Soil water balance under simulation studies indicated that potential ET was recorded comparatively higher with early sowing date than late sowing date under both irrigated un-irrigated mulched conditions. Similar trend was recorded with respect to transpiration under both irrigated and un-irrigated mulched conditions. Simulated soil evaporation was more in wider spacing than closer spacing. Similar trend was recorded with regard to simulated run-off. Predicted nitrate content (final) of irrigated soil decreased where under un-irrigated mulched conditions 15th April (D_1) sowing predicted lowest NO_3 leaching than later sowing dates. Under un-irrigated mulched conditions leached nitrate was nominal. Nitrogen denitrification was comparatively more under un-irrigated mulched conditions than irrigated condition.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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