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Evaluation of CropSyst Model to Simulate the Effect of Irrigation and Nitrogen Levels on Clusterbean

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

An experiment entitled "Evaluation of the CropSyst model to simulate the effect of irrigation and nitrogen levels on clusterbean" was carried out at village Bajju, Bikaner, Rajasthan during *kharif* season of 2016. The treatment comprising 3 levels of irrigation (100, 200 and 300 mm) and 4 levels of nitrogen (0, 20, 40 and 60 kg N/ha) comprising a total of 12 treatment combinations in split plot design with four replications. The simulation of CropSyst model was utilized to quantify and verify the interactive effect of different irrigation and nitrogen treatments on the productivity of clusterbean using measurements from field experiment. The soil of site are loamy sand having 86.3, 7.8 and 5.9 % of sand, silt and clay, respectively in 0-15 cm soil depth with pH 8.1 and low soil organic matter content (0.13%). The prediction of the model for seed yield and biomass was acceptable with 17.1 and 22.1 % of RMSE which may be considered good prediction by the model. However, the simulated N-uptake was over predicted by model and did not agreed with field measurements with 39.8% RMSE. The soil moisture content at different stages of growth was well simulated by CropSyst. The RMSE of moisture content ranged from 0.0123 to 0.0278 in clusterbean.

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1. INTRODUCTION

Rajasthan is predominantly a rainfed state and precipitation being major source of annual renewable water supply. The total water resources of state account for 45.09 BCM (billion cubic metre), consisting 33.94 BCM (billion cubic metre) share by surface water resources and 11.15 BCM (billion cubic metre) by groundwater resources. The overall utilization of water resources is 81% being 71% for surface water and 104% of groundwater resources. With the fast increasing population the water availability in the state is decreasing at an alarming rate and water scarcity is growing rapidly. According to an estimate, in the year 2001, the annual per capita water availability was 840 m^3 and expected to be as low as 439 m^3 by 2050 (Vision 2004a, 2004b, X^{th} Five Year Plan). The situation of groundwater resources is very critical in the state. Out of total 237 groundwater blocks of the state, the number of safe blocks reduced to 162 to only 32 from 1984 to 2004, whereas in the same period the numbers of dark blocks has increased from 22 to 140. At present ~ 80.4% of groundwater blocks of state fall under category of dark and critical. Water scarcity threatens food security for millions of people particularly in the arid and semi-arid regions. A major constraint to increase the food grain production in arid Rajasthan is limited surface water availability. Furthermore, the current irrigation systems in Rajasthan state are causing environmental problems of rising and declining groundwater levels, water logging and salinization.

In order to improve water management and its productivity it needs to reveal the cause–effect relationships between hydrological variables such as evaporation, transpiration, percolation and biophysical variables such as dry matter and grain yields under different eco-hydrological conditions [1]. Measurements of the required hydrological variables under field conditions are difficult, and need sophisticated instrumentation. Moreover, field experiments yielding site-specific information are very expensive, laborious and time consuming. However, suitable models like the CropSyst in combination with field experiments offer the opportunity to gain detailed insights into the system behaviour in space and time. CropSyst [2] is a process-based model to simulate crop growth and water dynamics in the soil-plant atmosphere continuum. The accuracy of these predictive models depends upon the proper identification of input parameters. Previous work done on improving water productivity through modeling approaches showed that the CropSyst model can be applied successfully for simulating clusterbean yield with recommended farmers practices [3]. However, little work has been done on validation of the model with different crop management scenarios. The study will offer future opportunities to evaluate the effects of management practices and climate variability on crop yields, water balance components and water productivity, which are impossible to assess at present due to limited work on simulation models in this region. Drawing on these insights, the study was planned to evaluate CropSyst model to simulate the effect of irrigation and nitrogen levels on clusterbean.

CropSyst is a multi-year, multi-crop, daily time step cropping systems simulation model developed to serve as an analytical tool to study the effect of climate, soils, and management on cropping systems productivity and the environment. CropSyst simulates the soil water budget, crop phenology, canopy and root growth, biomass production, crop yield, residue production and decomposition, soil erosion by water, and salinity. These processes are affected by weather, soil characteristics, crop characteristics, and cropping system management options including crop rotation, cultivar selection, irrigation, nitrogen fertilization, soil and irrigation water salinity, tillage operations, and residue management. The development of CropSyst started in the early 1990s. The motivation for its development was based on the observation that there was a niche in the demand for cropping systems models, particularly those featuring crop rotation capabilities, which was not properly served. Efficient cooperation among researchers from several world locations, a free distribution policy, active cooperation of model developers and users in specific projects, and careful attention to software design from the onset allowed for rapid and cost-effective progress. Another important factor was the advantage of learning from a rich history of crop modelling efforts. Attention to a balance between the incorporation of sound science in the models and the utilization of adequate software design practices has been a trait of CropSyst since the beginning of its development. In this regard, it shares somewhat common objectives with

APSIM [4,5], a modelling approach that has evolved to place substantial resources in the development of quality software engineering practices.

2. MATERIALS AND METHODS

An experiment on farmer field was conducted during *kharif* 2016 at village Bajju in Bikaner district of Rajasthan. Soil physical (texture and bulk density) and chemical (pH, EC, CEC, ammonical-nitrogen and nitrate nitrogen) properties of experimental field were determined up to 1.0 m depth following the standard procedures (Table 1). The sand, silt and clay contents were determined with Hydrometer method [6], bulk density with core method [7], EC was measured with conductivity meter and pH with pH meter [8], OC by Wet digestion method [9]. Ammonical nitrogen was determined by Nessler's method [10] and nitrate nitrogen was determined by Phenoldisulphonic acid method [11,12]. The field capacity was determined in the field by covering the fully saturated soil surface with a polythene sheet and measuring the moisture content after 24-72 hours depending on soil type. In order to ascertain the physico-chemical characteristics, soil samples were collected from different spots of the experimental field. Field was prepared with two disking, followed by harrowing and planking. The field experiment on clusterbean was laid out with 3 levels of irrigation i.e. 100, 200 an 300 mm and 4 levels of nitrogen i.e. 0, 20, 40 and 60 kg N ha^{-1} in split plot design with four replications. Clusterbean cultivar RGC 1038 was sown during August, 2016. The crop was sown at a spacing of 30 x 10 cm distance using 20 kg/ha seed rate. Half dose of nitrogen was applied as a basal dose through urea prior to sowing and the remaining half dose of nitrogen was top dressed through urea at second irrigation as per treatment which treatment (Nitrogen i.e. 0, 20, 40 and 60 kg N ha^{-1}). The irrigation was applied in the field as per treatments. The crop was harvested during last week of October, 2016. Plant phenological stages and climate factors were recorded during the crop season.

2.1 Description of CropSyst Model

CropSyst model will be applied to carry out the research study. The model has been developed to serve as an analytic tool to study the effect of cropping systems management on productivity and the environment. The version 4.15.24 of CropSyst crop model [13] was used to simulate yield and water productivity for clusterbean. The CropSyst model was calibrated on yield of clusterbean using the observed phenological parameters (emergence, flowering, grain filling and physiological maturity) and harvest index of clusterbean from the experiment. The other parameters for the crop file were taken as default with slight adjustments. These adjustments were made within the range from the reported elsewhere [14] so that the periodic crop growth like phenological stages, periodic biomass and final grain yield were matched with the experimentally observed values. The crop parameters used in the model are given in Table 2. During the first step simulated phenological stages (germination, flowering and physiological maturity) were matched with the observed by adjusting the degree days. The degree days were 300 for beginning of flowering, 350 for grain filling and 400 for physiological maturity, respectively.

3. RESULTS AND DISCUSSION

The various physical and chemical characteristics of the soil of the experimental site are given in Table 2. Model calibration was conducted following the procedure outlined by Hu et al. [15]. The model was initialized prior to sowing of clusterbean and calibrated parameters were adjusted for fertilizer nitrogen and irrigation treatments. Evaluation of model performance was carried out using statistical tool *ie*. root mean square error (RMSE). On an average, the prediction of the model for seed yield and biomass was acceptable with 17.1 and 22.1% in clusterbean (Tables 3 and 4) which may be considered good prediction by the model. However, the simulated N-uptake was over predicted by model and did not agreed with field measurements with 39.8% RMSE for clusterbean (Table 5). The soil moisture content of clusterbean at different stages of growth was well simulated by CropSyst. The RMSE of moisture content ranged from 0.0123 to 0.0278 in clusterbean (Table 6 and Fig. 1). These small values revealed that soil water flow was well simulated by CropSyst. As no systematic under or over estimation of moisture content was observed, the differences between the observed and simulated moisture content are contributed to the spatial heterogeneity and observation errors, which are inevitable under field conditions. Simulated value of moisture content was predicted well with observed values in the upper layers up to 100 cm. The index of agreement was 0.844 in top soil layer of 50 cm in clusterbean. The performance of CropSyst model was quiet satisfactory at low levels of nitrogen, *i.e*. 0 kg/ha and 20 kg/ha whereas there was some deviation between observed and simulated values in the response of CropSyst model to higher dose of nitrogen 60 kg N/ha for all parameters, *viz*. economic and biomass yield. This deviation in the experimental values at higher levels of nitrogen for economic and biomass yield might be due to reduction in N losses in the form of NH_3 volatilization [16] and also due to depletion in the form of exchangeable NH_4^+ N because of vigorous growth rate at vegetative stage of crop which tend to increase the rate of N uptake [17]. These characteristics of crops might not have been captured in the model

Table 1. General characteristics of the soil before sowing of clusterbean crop

Soil parameters	Depth (cm)				
	0-15	**15-30**	**30-45**	**45-60**	**60-100**
Sand (%)	86.3	85.7	84.9	84.3	83.7
Clay (%)	5.9	6.1	6.4	6.6	6.9
Silt (%)	7.8	8.2	8.7	9.1	9.4
Bulk density (g cm^{-3})	1.56	1.57	1.58	1.58	1.58
CEC (cmol kg^{-1})	3.1	3.4	3.5	3.9	4.1
pH	8.1	8.1	8.0	8.1	8.0
PWP (m^3 m^{-3})	0.074	0.076	0.079	0.081	0.083
FC (m^3 m^{-3})	0.152	0.155	0.159	0.161	0.163
Water content (m^3 m^{-3})	0.143	0.145	0.148	0.153	0.157
NO_3-N (kg N ha^{-1})	14.2	12.3	10.7	8.7	8.2
NH_4-N (kg N ha^{-1})	20.5	17.1	16.4	15.6	14.5
SOM (%)	0.130	0.110	0.095	0.080	0.060
EC (dS m^{-1})	0.175	0.170	0.160	0.155	0.147

Table 2. Crop parameters from the experiment used for calibration of clusterbean

Parameters	Value	Unit
Thermal time accumulation		
Base temperature	12	°C
Cutoff temperature	30	°C
Phenology		
Degree days emergence	80	°C days
Degree days maximum rooting depth	150	°C days
Degree days end of vegetative growth	200	°C days
Degree days begin flowering	300	°C days
Degree days begin filling	350	°C days
Degree days physiological maturity	400	°C days
Canopy growth		
Initial green leaf area index	0.011	m^2 m^{-2}
Maximum expected LAI	3.0	m^2 m^{-2}
Specific leaf area, SLA	28	m^2 kg^{-1}
Fraction of max. LAI at physiological maturity	0.80	
Leaf/stem partition coefficient, SLP	1.40	
Leaf water potential that begins reduction of canopy expansion	-800	J kg^{-1}
Leaf water potential that stops canopy expansion	-1200	J kg^{-1}
Harvest		
Unstressed harvest index (HI)	0.33	
Biomass translocation to grain fraction	0.23	
Root		
Maximum rooting depth	1.3	m
Root length per unit root mass	90	m kg^{-1}
Max. surface root density at full rooting depth	3.0	cm cm^{-3}
Curvature of root density distribution	2.0	

due to which simulated values were underestimated at higher levels of N *i.e.* 60 kg N/ha for both the estimated parameters, *viz.* economic yield and biomass.

Table 3. Comparison of observed and simulated seed yield (kg/ha) of clusterbean using CropSyst model

Nitrogen levels (kg ha^{-1})	Irrigation levels (mm)					
	Observed			Simulated		
	100	200	300	100	200	300
0	594	696	738	651	653	692
20	725	878	1016	659	1049	958
40	758	1079	1152	1072	1125	1073
60	778	1150	1165	1135	1180	1180
RMSE (%)	17.1					

Table 4. Comparison of observed and simulated biomass yield (kg/ha) of clusterbean using CropSyst model

Nitrogen levels (kg ha^{-1})	Irrigation levels (mm)					
	Observed			Simulated		
	100	200	300	100	200	300
0	2515	2496	2648	3111	3120	3234
20	2598	3149	3642	3150	4018	3754
40	2719	3868	4129	4078	4196	4079
60	2790	4124	4247	4219	4287	4287
RMSE (%)	22.1					

Table 5. Comparison of observed and simulated N uptake (kg/ha) of clusterbean using CropSyst model

Nitrogen levels (kg ha^{-1})	Irrigation levels (mm)					
	Observed			Simulated		
	100	200	300	100	200	300
0	25.1	26.5	27.5	32.2	31.5	32.7
20	31.0	36.3	43.2	34.9	36.3	35.5
40	33.6	50.3	53.5	45.3	38.9	40.2
60	34.4	54.6	55.3	45.6	40.6	37.8
RMSE (%)	39.8					

Table 6. Quantitative measures of model performance for soil moisture of clusterbean for calibration

Soil layer (cm)	RMSE	RRMSE (%)	Correlation coefficient	Index of agreement
0-100	0.0186	14.1	0.856	0.914
0-10	0.0278	25.2	0.597	0.712
10-20	0.0244	20.6	0.664	0.777
20-30	0.0200	16.3	0.828	0.869
30-40	0.0171	13.5	0.859	0.919
40-50	0.0148	11.3	0.906	0.945
50-60	0.0138	10.4	0.930	0.955
60-70	0.0123	9.1	0.953	0.964
70-80	0.0125	9.1	0.968	0.963
80-90	0.0140	10.0	0.966	0.955
90-100	0.0216	13.5	0.814	0.791

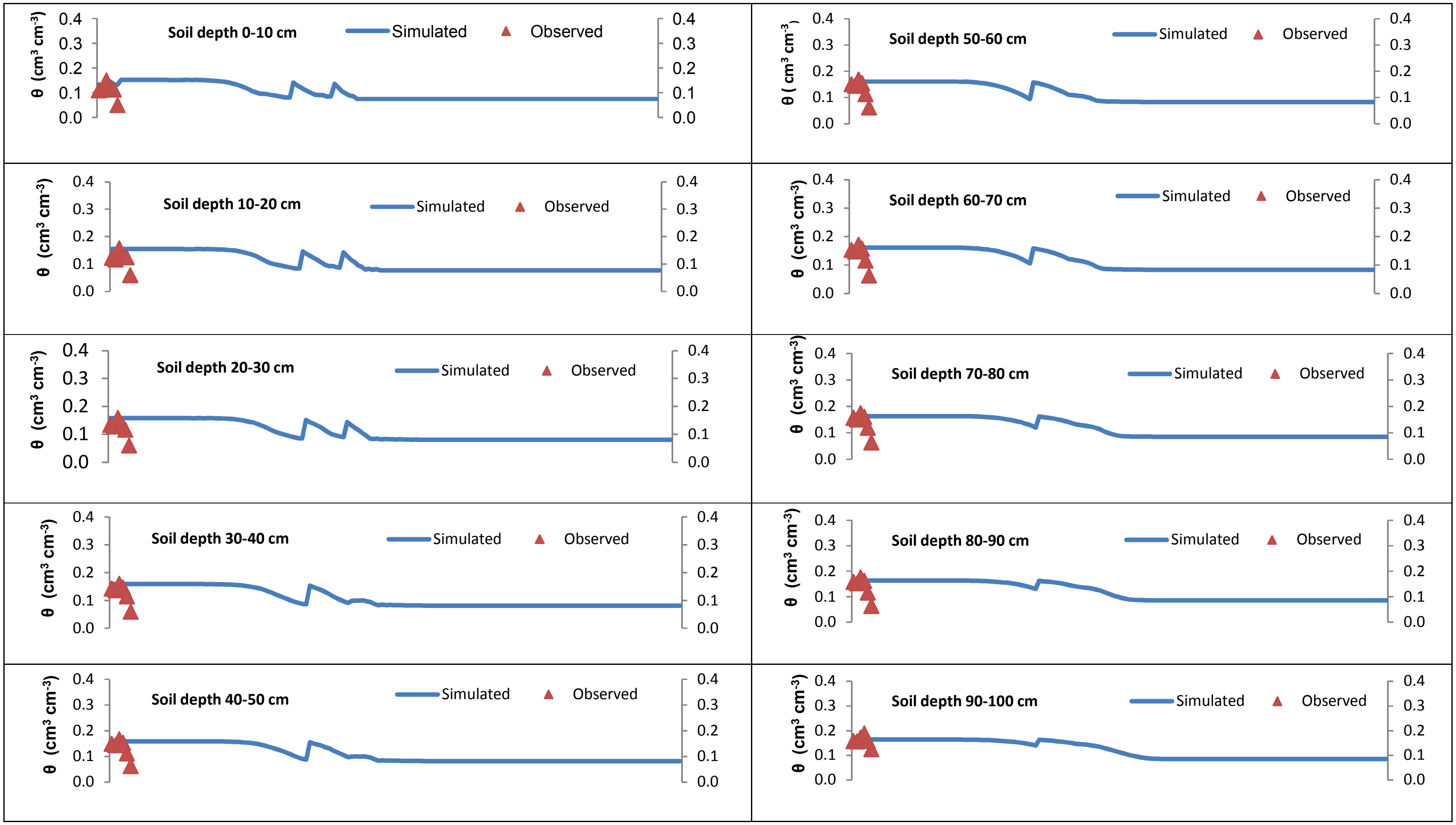

Fig. 1. Observed and simulated soil moisture content (θ) under clusterbean

The model responded well to limited levels of irrigation with significant *r* values between observed and predicted. CropSyst model did not take into account the effect of pre sowing irrigation on the economic and biomass yield of. This parameter might not have been incorporated in the model due to which the predicted values of economic yield and biomass at 0 and 40 kg N/ha levels are more or less equal whereas in actual field condition, pre-and post-sowing irrigation had a significant difference in economic yield of crops. The RMSE for economic and biomass yield was 0.15 t/ha and 0.71 t/ha which was 17.1 and 22.1% of the experimental mean, respectively, for clusterbean. These low values of RMSE indicated that the CropSyst model is accurate at predicting yield and biomass for clusterbean. Also, the higher *r* values for biomass and economic yield showed that the model is fit for predicting these two initial parameters for clusterbean, whereas the model over estimated N uptake.

4. CONCLUSION

Based on the results of one year experimentation, it may be inferred that water deficit and nitrogen availability are the important parameter for deciding the productivity of clusterbean in arid environment. In the present study irrigation of 200 mm with 40 kg N ha^{-1} in clusterbean was found most promising for getting higher yield. CropSyst model predicted the aboveground biomass, economic yield and moisture content accurately. Since, the model over estimated N-uptake, hence fine tuning is required in this regard. However, over all, it may be inferred that the CropSyst model could be applied to predict yield and biomass of clusterbean in irrigated north–western plain zone of Rajasthan in different management practices.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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