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Evaluation of cropsyst model for yield and water productivity of chickpea

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ABSTRACT

An experiment entitled "Evaluation of CropSyst model for yield and water productivity of chickpea" was conducted on farmers field during *rabi* 2012-13 at village Mainawali in Hanumangarh district of Rajasthan. The soils of the area are alluvial and calcareous in nature formed under arid and semi arid climate. The soils of site are brown to grayish brown and dark gray in colour, besides being calcareous and slightly alkaline in reaction having 67.7, 11.1 and 21.0 % of sand, clay and silt, respectively in 0-15 cm soil depth with pH 8.09 and low soil organic matter content. The simulated and observed green area index differs with field measurements at all stages. The simulate yield of chickpea were closer to the observed yield. The total water applied in chickpea was 415 mm out of this 356.5 mm consumed in ET. Thus, ET constituted 86% of total water applied and deep drainage constituted 12% and rest 2% stored as residual soil moisture.

Key words: Chickpea, CropSyst, Model, Simulation.

INTRODUCTION

Freshwater in sufficient quantity and adequate quality is a prerequisite for human societies and natural ecosystems (Costanza and Daly, 1992). Agriculture is the largest user of water with 65–75% of freshwater being currently used for irrigation (Bennett, 2000). Furthermore, the scarcity of water for agriculture are heightened by groundwater mining, escalating cost of developing new irrigation facilities, low water productivity of existing resources, increasing water pollution and degradation of water related ecosystems (Rosegrant *et al*., 2009). Water productivity, a concept expressing the value or benefit derived from the use of water, includes various aspects of water management and is very relevant for arid and semi-arid regions. It can be expressed in terms of grain (or seed) yield per amount of water used in different processes such as transpiration, evapotranspiration and percolation and provides a proper diagnosis of where and when water could be saved. Increasing water productivity is particularly appropriate where water is scarce compared with other resources involved in production.

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, consisting 33.94 BCM share by surface water resources and 11.15 BCM 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) (Kumar *et al*., 2016). 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. The Hanumangarh district, located in the North Western part of Rajasthan State, represents the typical example of canal water misuse leading to rising groundwater levels, water logging and secondary salinization. These water management issues are very complex, and must be addressed by better planning and management. (Rathore *et al*., 2010).

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 (Singh *et al*. 2006). Measurements of the required hydrological variables under field conditions are difficult, and need sophisticated instrumentation. Moreover, field experiments yielding site-specific information are very

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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. Simulation models are an important tool to understand plant–soil interactions on water balance components and their effects on crop growth. They can assist field experimentation because direct measurement of all elements of the water balance (evaporation, transpiration, drainage, runoff and profile water content change) is often not possible. CropSyst has been applied to perform risk and economic analyses of scenarios involving different cropping systems, management options and soil and climatic conditions. CropSyst (Stockle and Nelson, 1999) is a process-based model to simulate crop growth and water dynamics in the soil-plant atmosphere continuum. It has been widely used for cereals and other cropping systems (Stockle *et al.*, 1994).The accuracy of these predictive models depends upon the proper identification of input parameters. As the information pertaining to water productivity of chickpea and use of simulation models are non-existent for Indira Gandhi Nahar Pariyojana stage-I command area. Drawing on these insights, the study was planned to evaluate yield and water productivity of chickpea at scheme level with objectives to quantify water balance and to calculate water productivity of chickpea.

MATERIALS AND METHODS

An experiment on farmers field was conducted during *rabi* 2012-13 at village Mainawali in Hanumangarh district of Rajasthan (74° 20’34"E - 074° 20’60" E longitude and 28° 37’62" N - 29° 21’39" N latitude and 235 m above mean sea level). 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. The sand, silt and clay contents were determined with Hydrometer method (Bouyoucos, 1962), bulk density with core method (Blake and Hartge, 1986), EC was measured with conductivity meter and pH with pH meter (Richards, 1954), OC by Wet digestion method (Walkley and Black, 1934). Ammonical nitrogen was determined by Nessler’s method (Peech *et al.*, 1947) and nitrate nitrogen was determined by Phenol disulphonic acid method (Harper, 1924 and Prince, 1945). 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. The ground water at the experimental site was less than 10 m deep and was determined with piezometer. Daily weather data on maximum and minimum temperature, maximum and minimum relative humidity, pan evaporation, sunshine hours and rainfall during the crop growth period were recorded at meteorological observatory situated near experimental site (Table 1). Field was prepared with two disking, followed by harrowing and planking. Chickpea cultivar GNG669 was sown on 25 November, 2012 at a spacing of 30 x 10 cm distance using 80 kg/ha seed rate. Nitrogen @ 20 kg/ha and P_2O_5 @ 40 kg/ha were applied to the crop. Entire nitrogen and phosphorus was applied at the time of sowing of the crop. Plant phenological stages and climate factors were recorded during the crop season.

Description of CropSyst model: The version 4.15.24 of CropSyst crop model (Stockle *et al.* 2003) 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 (Jalota *et al.*, 2006) 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 data by adjusting the degree days. The degree days were 165 for beginning of flowering, 200 for grain filling and 500 for physiological maturity, respectively.

CropSyst is a multi-year, multi-crop, daily time step cropping systems simulation model developed to serve as

Table 1: Monthly meteorological data during crop season.

	Temperature (°C)		Relative humidity (%)		Total Rainfall	Pan Evaporation	Sunshine hours
Month	Max	Min	RHMax	RHMin	(mm)	(mm)	(h/day)
November	28.31	10.95	90.00	57.63	0.00	56.20	6.38
December	21.45	6.89	94.13	63.81	4.80	43.20	5.82
January	19.38	7.28	95.94	62.10	6.00	43.00	5.18
February	22.83	9.34	95.04	63.89	58.80	52.40	6.03
March	31.09	13.71	84.84	44.26	4.40	118.50	8.02
April	36.57	18.30	58.53	31.57	32.10	165.60	7.86
May	43.54	23.93	40.84	19.97	0.00	250.20	10.32

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

Parameters	Value	Unit
Thermal time accumulation		
Base temperature	05	°C
Cutoff temperature	30	°C
Phenology		
Degree days emergence	110	°C days
Degree days maximum rooting depth	230	°C days
Degree days end of vegetative growth	250	°C days
Degree days begin flowering	285	°C days
Degree days begin filling	450	°C days
Degree days physiological maturity	850	°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	25	m^2 kg^{-1}
Fraction of max. LAI at physiological maturity	0.8	
Leaf/stem partition coefficient, SLP	3	
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)	0.31	
Biomass translocation to grain fraction	0.30	
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	0.10	

Table 3: General characteristics of the soil before sowing of chickpea crop.

Soil parameters	Depth (cm)				
	0-15	15-25	25-50	50-75	75-100
Sand (%)	67.75±6.30	67.61±6.32	67.45±6.31	67.23±6.26	66.95±6.23
Clay (%)	11.14±1.73	11.21±1.75	11.27±1.76	11.41±1.74	11.51±1.72
Silt (%)	21.01±4.60	21.17±4.63	21.25±4.67	21.36±4.61	21.58±4.66
Bulk density(g cm^{-3})	1.44±0.06	1.45±0.06	1.46±0.07	1.47±0.07	1.48±0.07
CEC(cmol kg^{-1})	5.39±0.56	5.53±0.55	5.61±0.54	5.77±0.52	5.91±0.58
pH	8.09±0.15	8.04±0.18	7.95±0.20	7.89±0.21	7.86±0.21
PWP (m^3 m^{-3})	0.085±0.01	0.086±0.01	0.088±0.01	0.089±0.01	0.092±0.01
FC (m^3 m^{-3})	0.186±0.01	0.187±0.01	0.189±0.01	0.191±0.01	0.195±0.01
Water content(m^3 m^{-3})	0.173±0.015	0.177±0.401	0.181±0.016	0.186±0.015	0.193±0.015
NO_3-N (kg N ha^{-1})	20.18±1.60	18.28±1.51	16.24±1.54	14.20±1.57	14.02±1.46
NH_4-N (kg N ha^{-1})	55.65±4.24	49.98±4.17	49.20±4.50	49.05±5.18	47.37±4.90
SOM (%)	0.295±0.074	0.312±0.079	0.290±0.072	0.272±0.073	0.261±0.074
EC (dS m^{-1})	0.175±0.073	0.173±0.067	0.173±0.063	0.164±0.066	0.165±0.063

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 eosion by water and salinity. These processes are affected by weather, soil characteristics, crop characteristics and copping 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 (McCown *et al.*, 1996, Keating *et al.*, 2003), a modelling approach that has evolved to place substantial resources in the development of quality software engineering practices. CropSyst model was 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.

RESULTS AND DISCUSSION

The various physical and chemical characteristics of the soil of the experimental site are given in Table 3. Model calibration was conducted following the procedure outlined by Hu *et al.*, (2006). For calibration of chickpea, data of the green area index (GAI), seed yield, above ground biomass (AGB) and N-uptake were used to determine the best crop model parameters. The simulated GAI, seed yield, above ground biomass and N-uptake were closer to the observed values of chickpea during the season. The simulated and observed GAI differ with field measurements at early stages. However, the maximum GAI of 1.39 was observed at 60 DAS which was slightly lower than simulated value (2.69). The absolute and relative error was 0.87 and 83, respectively (Table 4).

The seed yield of chickpea was simulated with CropSyst model by inputting the observed data on duration of different phenol-phases during the experiment under field conditions. The simulate yield (2281 kg/ha) of chickpea were closer to the observed yield of 2292 kg/ha as it is evident from the 11% absolute error (Table 5). Simulations of early chickpea aboveground biomass development matched the field data reasonably well. Final above ground biomass, however, was over estimated by the model. The drop in above ground biomass of the chickpea around late April was not properly captured by the model. As it was set for optimal conditions, CropSyst could not properly simulate the late season plant stress that impaired growth on these sites. Although chickpea yield were simulated well and it did not respond to variation with correlation close to one. The reason for the moderate variation in yield was a very low annual variation in measured chickpea yield. The simulated N-uptake (140 kg/ha) was higher to observed N-uptake (110 kg/ha) with 29% absolute error. Increased uptake of N seems to be due to the fact that uptake of nutrient is a product of biomass accumulated by particular part and its nutrient content (Kumar *et al.,* 2016).

The total water applied in chickpea was 415 mm out of this 356.5 mm may consume in ET. Thus, ET constituted 86 % of total water applied and deep drainage constituted 12 % and rest 2 % stored as residual soil moisture.

Table 4: Observed and simulated values for GAI of chickpea crop.

Stage	Green area index (m^2 m^{-2})	
	Observed	Simulated
30 DAS	0.553	0.150
60 DAS	1.399	2.692
90 DAS	1.173	1.824
Absolute error	0.87	
Relative error	83	

Table 5: Quantitative measures of model performance for yield, above ground biomass and N-uptake of chickpea crop.

Particular (kg/ha)	Observed	Simulated	Absolute error	Relative error
Seed yield	2292	2281	11	0.48
AGB	6582	7359	777	12
N-uptake	110	140	29	27

Table 6: Soil water balance components, yield and water productivity of chickpea.

Component	Chickpea
Inputs	
Irrigation (mm)	309
Rainfall (mm)	106
Total (mm)	415
Losses	
ET (mm)	356.5
Drainage (mm)	48.5
Stored soil moisture (mm)	10
Economic yield (kg ha^{-1})	2292
Water productivity (kg m^{-3})	0.55

Table 7: Quantitative measures of model performance for soil moisture under chickpea.

Soil layer, cm	RMSE	RRMSE	Correlation	Index of agreement
0-100	0.0359	17	0.97	0.89
0-10	0.0333	19	0.99	0.93
10-20	0.0386	20	0.98	0.88
20-30	0.0380	19	0.97	0.88
30-40	0.0376	18	0.98	0.88
40-50	0.0366	17	0.98	0.89
50-60	0.0404	19	0.95	0.86
60-70	0.0400	19	0.94	0.84
70-80	0.0309	14	0.98	0.90
80-90	0.0321	15	0.98	0.89
90-100	0.0291	13	0.97	0.89

Results showed that $1/5^{th}$ of total water applied lost by deep drainage (Table 6) with water productivity of 0.55 kg m^{-3}. The seasonal water loss (Soil water evaporation + transpiration + drainage below root zone) matched reasonably well the measured values (Irrigation + rainfall) for chickpea. Measured water loss ranged from 800 to 1000 mm for cotton (Aujla *et al.,* 1991) and 400 to 450 mm for wheat (Arora *et al.*, 1997). A close relationship between simulated and measured water loss values under different crops suggest that the simulation of water balance components were realistic with the model and can be used for assessing water loss components in cropping systems including the intervening bare period. It is significant to note that there was net depletion of soil water storage in long duration crops like cotton and wheat. These results show trends and magnitudes of soil water depletion similar to field observations (Jalota *et al.*, 1985).

The value of RMSE of moisture content ranged from 0.0423 to 0.0562. These values reveal that soil water flow was well simulated by CropSyst model. Simulated value of moisture content predict well with observed values in 0-100 cm with 0.0359, 0.97, 0.89 and 0.99 of RMSE, correlation and index of agreement, respectively (Table 7).

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