

Optimizing Irrigation and Fertigation Levels to Enhance the Productivity of Cotton Through the Use of DSSAT-CROPGRO-Cotton Model

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ABSTRACT

The widespread use of conventional irrigation practice i.e., flood irrigation needs to replace with more water conserving practices like drip irrigation. In order to enhance cotton productivity, it is necessary to optimize water and nutrient levels through resource conservation techniques. Therefore, a field experiment was conducted to evaluate the performance of the DSSAT-CROPGRO-Cotton model under varying irrigation and fertilizer regimes during the *kharif* season of 2020. The experiment was assigned with Randomized complete block design, including three subsurface irrigation levels: at 60 % ETc (I₁), 80 % ETc (I₂), 100 % ETc (I₃), coupled with two fertigation levels: 75% (F₁) and 100 % (F₂) recommended dose

of nitrogen (112.5 kg N/ha). Additionally, 100% RDN (105 kg N/ha) with surface flood irrigation and 100 % RDN (112.5 kg N/ha) with surface drip irrigation with were used as control. Results revealed that the highest seed cotton yield (3393 kg/ha) was recorded with subsurface fertigation of 100 % RDN (I₂F₂) with irrigation at 80% ETc, at par to fertigation of 100 % RDN with 100% ETc (I₃F₂). The DSSAT-CROPGRO-cotton model showed high accuracy, with higher d-stat (above 0.91) for simulating various growth, phenology and yield parameters. Thus, lower error values obtained under simulation results further supported the model's applicability under diverse inputs and management conditions.

Keywords Cotton, CROPGRO, Drip, Fertigation, Irrigation, Simulation.

INTRODUCTION

Cotton, a major cash crop of India and has great potential to perform better under limited water resources. In India, cotton is being cultivated in three diverse zones of India viz., central zone (Gujrat, Maharashtra and Madhya Pradesh), northern (Punjab, Haryana and Rajasthan) and southern (Andra Pradesh, Karnataka, Telangana and Tamil Nadu). In south-west region of Punjab, cotton is second major crop of kharif (summer) season after rice. From the perspective of crop diversification, area under cotton crop maybe increased to ~7 lakh ha (as a potential area) in this

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part of Punjab (Singh *et al.* 2020). Cotton stands out as a superior crop in various agricultural landscapes due to its versatility and economic advantages. With better resources utilization ability and adaptation capacity to diverse climates, the cotton cultivation has become a resilient choice for farmers. Its high market demand, coupled with huge applications in textile industries, ensures consistent and lucrative returns to its growers.

Efficient irrigation management, particularly in the critical stages of cotton growth, significantly influences water uptake, nutrient absorption, and overall plant health. Timely and adequately applied irrigation positively impacts cotton's reproductive phase, enhancing flower and boll development. Moreover, adjusting with depth of irrigation water in accordance with the crop's water requirements during different growth stages ensures optimal root development and water use efficiency. By carefully balancing the timing and depth of irrigation, cotton plants are better equipped to withstand environmental stressors, ultimately leading to improved yields and overall crop performance. This nuanced understanding of irrigation management is essential for maximizing cotton productivity and resource conservation in agricultural practices. However, at present, availability of quality irrigation water is declining at an alarming rate besides contamination of both surface and ground water resources. Varying trends of onset of monsoon affect the scheduling of irrigation in various field crops. Changes in precipitation patterns also declining agricultural productivity by affecting water quantity and quality. Shortage of quality irrigation water and faulty irrigation scheduling jointly contribute to the low productivity of cotton in Punjab (Singh *et al.* 2019). Traditionally, method of flood irrigation application resulting in a significant loss of water and nutrients. Necessitates for proper management of the irrigation for achieving maximum irrigation water use efficiency.

Cotton (*Gossypium hirsutum* L.) raised under flood irrigation not only wastes precious water resources but also leads to nutrient leaching, excessive vegetative growth, and delayed maturity. Drip irrigation coupled with fertigation holds a greater promise, specifically for the arid and semiarid regions of north

western India, where brackish underground water is unfit for crop production (Singh *et al.* 2018). To avoid water wastage, drip irrigation method has been an effective way of supplying frequent and uniform application of water to cotton. Fertigation in fact is an accurate delivery of chemical fertilizer through water to fulfil current plant requirements. It might be an encouraging practice for a crop like cotton whereby fertilizer and water losses can be significantly reduced but N efficiency increased (Singh *et al.* 2018). Fertigation facilitates elasticity in time of nutrient application in response to plant demand. Fertigation, therefore have been a viable option for arid and semi-arid regions, facing acute shortage of good quality underground water for cultivation of crops.

In arid and semi-arid zones of north-western India including Punjab, drip irrigation can assist in getting much promising results. In previous studies, lot of work have been done on surface drip fertigation but subsurface drip fertigation is an efficient and advanced method of irrigation based on the crop water requirements. The sub-surface system is comprised of lateral pipes laid under the soil with emitters spaced at regular spacings to supply the irrigation water directly to the root zone; hence eliminating the evaporation, surface runoff losses and also helps in reducing the surface infiltration, such as crusting, over-saturation condition in comparison to surface irrigation systems. Further, there is no issue of removing the drip pipeline after harvesting of each crop. Hence, it is more cost effective than other methods of irrigation including surface system. Besides, the sub-surface drip system decreases nitrate leaching facilitates better weed control, increases crop yield and thus higher monetary returns. Therefore, improved water and nitrogen application in cotton cultivation, sub-surface drip fertigation offers great potential for managing right quantity, exact timing and placement of irrigation water and fertilizers at desired levels.

The crop modelling is a quantitative approach to estimate the crop growth behavior, development and yield. The crop growth simulation models are effective tools to understand the crop growth, development and yield under varying climatic, edaphic, hydrologic and agronomic factors (Mishra *et al.* 2015) for different levels of genotype, crop, farming system,

environment, region. The crop growth simulation models also have potential for accurate evaluation of individual and/or joint effects of climatic, edaphic, hydrologic and agronomic factors on crop growth, development and yield (Mishra *et al.* 2015). The DSSAT-CROPGRO-cotton model is simulation algorithm maintained within the decision support system for agro-technology transfer (DSSAT) cropping system model. Already, it has been evaluated to simulate irrigation water needs. Both the excessing and deficit irrigation is harmful for the crop. Although, crop response to irrigation varies at different phenological stages. Irrigation water stagnated in the field during early crop establishment period cause plant death and thus, decreases the plant population. Similarly, at active growth periods leads to cell damage and absorption of flower and the fruiting bodies. Whereas, over saturated fields during the reproductive stages create crop wilting and sometimes prolonged conditions cause death of entire plants. The detrimental impacts of the deficit irrigation may be clearly notified on various physical and physiological parameters of crop. The shrinkage of leaf area, reduced plant weight, abnormal root development have been recorded by many researchers (Baksh *et al.* 2019). Likewise, the reduced rate of transpiration, photosynthesis, relative water content etc. have been reported.

Now days, there is huge untapped potential in agriculture for precise and real time irrigation and nutrient application both temporally and spatially. It is not only laborious but also expensive to study yield responses to different irrigation regimes in the field or under more controlled conditions. On the other hand, utilization of crop simulation models for deciding the amount and frequency of water and nutrient application through fertigation in drip system would be a proactive strategy for precision agriculture. Therefore, in present study, we explore the potential of DSSAT (V. 4.8) model to evaluate the effect of various input levels and management factors on the phenological development, seed cotton yield and above ground accumulation.

MATERIALS AND METHODS

The DSSAT-CROPGRO-cotton model

In India, DSSAT is a crop simulation model widely

used for more than 42 crops until the latest version (4.8). This model comprises of various modules for different crops, but in this study, CROPGRO-cotton module was implemented. This CROPGRO-module was developed by the combined approach of University of Florida and University of Georgia. It has the potential to simulate the growth and development of many crops viz., legumes, cruciferous, fodder and fiber. The CROPGRO-cotton model simulates the crop development process based on the accumulated photothermal units between various crop growth stages such as emergence, appearance of first leaf, flower, seed, physiological maturity. (Thorp *et al.* 2014) and simulates C assimilation individually into various plant parts like root, stem, leaf, bolls, seed. by using C assimilation approach given by Farquhar *et al.* 1980. Besides, it simulates the response of different management practices, cultivars, soil properties, root growth. It calculates daily evaporation based on Penamn-Moneith equation (Ritchie 1972) and soil water balance based on tipping bucket approach and this model simulates the growth and development of cotton crop on a daily scale whereas photosynthesis is simulated on an hourly basis (Boote and Pickering, 1994).

Site and soil description

The layer wise physio-chemical characteristics of soil has been presented in Table 1. The experimental site had sandy loam soil texture which contains 76.2 % sand, 14.0 % silt and 9.8 % clay and have organic carbon in the range of (0.31-0.61 %), available nitrogen (125.44-263.40 kg/ha), available phosphorus (20.83-38.10 kg/ha), available potassium (73.92-230.72 kg/ha), Iron (8.7-9.55ppm), Manganese (13.48-14.38 ppm), Zinc (2.78-2.89 ppm), copper (0.12-0.15 ppm), bulk density (1.53-1.68 g/cm³), CEC (8.04-8.44 Cmol/kg) and field capacity (20-23 cm/cm³).

Treatment details

Experiment was carried out in Randomized block design with three replications comprised of three irrigation regimes (60 % ETc (I₁), 80 % ETc (I₂), 100 % ETc (I₃)] and two fertigation doses [75 % RDN of drip fertigation (F₁), 100 % RDN of drip fertigation (F₂) i.e., 112.5 kg N/ha] along with two control treat-

Table 1. Physio-chemical characteristics of the experimental site.

Depth	0-15	15-30	30-45	45-60	60-75	75-90
pH (1:2)	7.18	9.2	8.14	7.95	7.62	7.16
OC (%)	0.61	0.57	0.51	0.4	0.37	0.31
N (kg/ha)	263.4	238.33	200.7	150.52	125.44	125.44
P (kg/ha)	38.1	38.08	32.5	25.76	22.32	20.83
K (kg/ha)	230.72	194.88	156.8	96.32	80.64	73.92
Fe (ppm)	9.55	9.52	8.99	8.92	8.7	8.69
Mn (ppm)	14.38	14.12	14.11	13.96	13.95	13.48
Zn (ppm)	2.89	2.88	2.87	2.88	2.87	2.78
Cu (ppm)	0.15	0.15	0.14	0.13	0.12	0.12
Saturated upper limit (cm/cm ³)	40	39	38	37	38	38
Bulk density (g/cm ³)	1.53	1.55	1.56	1.6	1.65	1.68
CEC (Cmol/kg)	8.31	8.04	8.01	7.99	8.42	8.44
Field capacity (cm/cm ³)	20	20.4	20.8	21.7	22.8	23

Note. pH: potential of hydrogen, OC: organic carbon, N: available nitrogen, P: available phosphorus, K: available potassium.

ments [Control 1: Surface flood irrigation with 100 % RDN; 105 kg N/ha (C₁), Control 2: Subsurface flood irrigation with 100 % RDN i.e., 112.5 kg N/ha (C₂)]. All the recommended cultural and plant protection measures were adopted throughout the crop growing season (https://pau.edu/content/ccil/pf/pp_kharif.pdf). Periodical observations on phenology, growth and yield attributes were recorded. The DSSATCROPGRO-cotton (v.4.6) model was calibrated using field experimental data recorded during 2019 and validation was done with second year experimental data recorded during 2020.

Calibration and validation of DSSAT-CROPGRO-cotton model

The DSSAT-CROPGRO-cotton model requires various site-specific input files including the soil file (soil texture, slope, albedo, color, upper and lower drainage limits, saturated water content, hydraulic conductivity, organic C content, bulk density and total soil N), the crop management file (including the planting date and planting method, sowing depth, seed rate, plant population, row spacing, cultivar characteristics, tillage type, tillage depth and dates, amount, time and method of irrigation, fertilizer doses, time and method of application, date and method of harvesting), and a daily weather. Model calibration refers to the adjustment of inbuilt genetic coefficients of model in order to bring close match between the simulated and actual experimental values. The field

experiment conducted at PAU Regional Research Station, Faridkot during 2019 has been used for calibration. The ground truth data collected from field experiment conducted during the year 2020 were used for validation of DSSAT-CROPGRO-cotton model.

Description of genetic coefficients

The cotton genotypes (RCH773) selected in this investigation were not available in the inbuilt DSSAT database therefore, it was added as a new cultivar within the genotype database of DSSAT model for calibration. During the calibration process, the cultivar (COGRO047.CUL) and the ecotype (COGRO045.ECO) parameters were adjusted to derive the desired cultivar specific genetic coefficients. Various cultivar parameters were adjusted during model calibration and the selected coefficients were presented in Table 2.

Model parametrization

The model parameterization consists of a group of parameters which simulates the crop growth and yield parameters according to local environment. The DSSAT-CROPGRO-cotton model has specific parameters associated with crop species, ecotypes and cultivars that calculate thermal unit accumulation for different crop developmental stages. Initial field conditions related to soil physical and chemi-

Table 2. Derived genetic coefficients of cotton cultivar RCH 773 for DSSAT-CROPGRO-cotton model.

Sl. No.	Genetic coefficient	Abbreviations	Units	RCH 773
Crop phenology and development				
1	Photothermal days from emergence to flower appearance	EM-FL	Photothermal days	48.5
2	Photothermal days from beginning flower to beginning boll	FL-SH	Photothermal days	14.7
Crop growth attributes				
3	Photothermal days from beginning flower to beginning seed	FL-SD	Photothermal days	19.3
4	Photothermal days from beginning seed to beginning maturity	SD-PM	Photothermal days	51.50
5	Time between first flower (R1) and end of leaf expansion	FL-LF	Photothermal days	74.00
6	Maximum leaf photosynthesis rate	LFMAX	Mg/CO ₂ /m ² /s	1.05
7	Specific leaf area	SLAVR	Cm ² /g	193.0
8	Maximum size of full leaf	SIZLF	Cm ²	332.0
9	Maximum fraction of daily growth partitioned to seed+ shell	XFRT	#	0.72
Crop yield attributes				
10	Maximum weight per seed	WTPSD	g	0.200
11	Photothermal days for seed filling per individual seed	SFDUR	Photothermal days	37.5
12	Average seed numbers per boll	SDPDV	Number/pod	28.00
13	Photothermal days to reach final boll head	PODUR	Photothermal days	12.2
14	Threshing percentage (maximum ratio of [seed/(seed+shell)])	THRSH	Percentage	96.0

cal characteristics were measured with soil sampling method. For the simulation of soil-water-nutrient dynamics in DSSAT model is based on the Century model (Ritchie *et al.* 2009). Three separate irrigation levels were created in DSSAT for surface flood, surface drip and subsurface drip systems. In subsurface drip, the water table depth was maintained to 30 cm while for surface flood and surface drip water depth was not controlled following Liu *et al.* 2013. Specific quantity of irrigation water computed equivalent to different levels of the crop evapotranspiration (ETc) was applied on specified dates as per treatments. The root growth factor (RGF) was determined as,

$$RGR = [1 - \exp(-0.02 * DLC)]$$

where, DLC is centre of depth of each layer deeper than 20 cm = 0.55 and DLC is 1 for soil layer shallow than 20 cm (Uryasev *et al.* 2004).

Model evaluation

Model evaluation was performed by graphical comparison of the mean values of measured and simulated phenological stages. Maximum leaf area index (LAI), plant height, seed cotton yield, and

aboveground biomass were compared with measured yields. The simulated results obtained during 2020 were evaluated by comparing phenology, growth, and yield attributes recorded from field experiments conducted during 2019.

RESULTS AND DISCUSSION

Model response to crop phenology

The deviation between observed and simulated days taken to anthesis was to -6 to 2 and -1 to 3 during 2019 and 2020 respectively under different treatments (Table 3). Likewise, for days taken to first boll day, the deviation was -1 to 4 for 2019 and -6 to 5 for 2020. Similarly, the deviation for days taken to physiological maturity lied between -4 to 8 and -10 to 2 during 2019 and 2020 respectively. Likewise, LAI -0.14 to 0.72 in 2020 and for 2019 it was -0.3 to 0.4 and it ranged from -0.52 to 0.30 and -0.64 to 0.11 during 2019 and 2020 respectively for canopy height. Mishra *et al.* 2021 also revealed the deviation between observed and simulated days for anthesis was 0 to 3 days (2015), 1 to 4 days (2016) and 0 to 3 days (2017) in cotton.

Table 3. Comparison between observed and simulated phenological parameters of cotton.

Obs (2019)	Sim (2019)	Anthesis (days)			Physiological maturity (days)						
		Dev (2019)	Obs (2020)	Sim (2020)	Dev (2020)	Obs (2019)	Sim (2019)	Dev (2019)	Obs (2020)	Sim (2020)	Dev (2020)
65	67	-2	65	66	-1	177	178	-1	170	180	-10
67	65	2	67	68	-1	179	173	6	173	175	-2
58	64	-6	63	62	1	166	165	1	165	164	1
60	64	-4	64	64	0	171	172	-1	167	165	2
62	66	-4	66	63	3	173	177	-4	169	171	-2
72	73	-1	74	72	2	185	187	-2	179	184	-5
69	68	1	72	70	2	183	175	8	176	174	2
70	72	-2	73	71	2	184	185	-1	177	186	-9

Table 3. Continued.

Obs (2019)	Sim (2019)	Leaf area index			Plant height (m)						
		Dev (2019)	Obs (2020)	Sim (2020)	Dev (2020)	Obs (2019)	Sim (2019)	Dev (2019)	Obs (2020)	Sim (2020)	Dev (2020)
3.4	3.2	0.2	2.7	2.8	-0.1	1.5	2.1	-0.6	1.9	2.4	-0.5
3.5	3.5	0.0	3.0	2.8	0.1	1.7	1.8	-0.1	1.8	1.8	0.0
3.2	3	0.2	2.2	2.1	0.1	1.3	1.2	0.1	1.3	1.1	0.2
3.3	3.5	-0.2	2.9	2.7	0.1	1.4	1.5	-0.1	1.5	1.2	0.3
3.5	3.1	0.4	3.2	3.2	-0.1	1.7	1.7	0.0	1.8	1.6	0.2
3.5	3.6	-0.1	3.6	3.7	-0.1	1.7	2.0	-0.3	1.8	1.7	0.1
3.5	3.3	0.2	3.0	2.3	0.7	1.7	1.9	-0.2	1.6	1.8	-0.2
3.6	3.9	-0.3	3.1	3.0	0.1	1.8	2.3	-0.6	1.8	1.9	-0.1

Model response to Above ground biomass and seed cotton yield

The deviation between observed and simulated above ground biomass was -286 to 49 kg/ha for 2020 and -441 to 443 kg/ha for 2019. Likewise for year 2019, the seed cotton yield was deviated in the range of -206 to 422 kg/ha and it was -363 to 399 kg/ha for 2020 (Table 4). Mishra *et al.* 2021 also observed the deviation between observed and simulated days for

above ground biomass within the range of 55-122 kg/ha during 2015 and for yield the deviation was -27 to 144 kg/ha.

Evaluation of model for phenology of cotton

In the CROPGRO-cotton model, developmental stages were predicted as a function of temperature, day length, and cultivar specific parameters (Boote *et al.* 1998). The study revealed the days taken to

Table 4. Comparison between observed and simulated above ground biomass and seed cotton yield.

Obs (2019)	Above ground biomass (kg/ha)			Seed cotton yield (kg/ha)							
	Sim (2019)	Dev (2019)	Obs (2020)	Sim (2020)	Dev (2020)	Obs (2019)	Sim (2019)	Dev (2019)	Obs (2020)	Sim (2020)	Dev (2020)
1454	1740	-286	1672	1814	-142	2551	2710	-159	2565	2928	-363
1662	1650	12	1888	2051	-163	3195	3160	35	3032	3100	-68
1179	1229	-50	1339	1561	-222	2222	2428	-206	2292	2465	-173
1283	1426	-143	1533	1974	-441	2504	2700	-196	2441	2364	77
1684	1850	-166	1858	1580	278	3104	2682	422	2886	2690	196
1733	1685	48	1942	2051	-109	3429	3160	269	3393	3507	-114
1882	2000	-118	2109	1666	443	3150	2854	296	3144	2745	399
1909	1860	49	2141	2212	-71	3502	3549	-47	3272	3540	-268

Table 5. Error analysis for days taken to anthesis, First boll day and Physiological maturity, Leaf area Index (LAI), Plant height, Seed cotton yield (SCY) and Above ground biomass (ABG).

Error Analysis		Mean _Obs	SD _Obs	Mean _Sim	SD _Sim	R	Student 't'	MA E	MB E	RMSE	d-Stat
Anthesis	2019	69.38	5.01	67.75	3.33	0.94	0.02	2.63	2.38	3.14	0.995
	2020	68.00	4.34	67.00	3.82	0.94	0.10	1.50	-1.00	1.73	0.999
First boll day	2019	88.50	4.81	87.00	5.24	0.96	0.02	1.75	-1.50	2.00	0.999
	2020	85.00	3.51	85.13	6.66	0.88	0.93	3.38	0.13	3.69	0.996
Physiological maturity	2019	177.25	6.82	176.50	7.09	0.82	0.62	3.00	-0.75	3.94	0.999
	2020	172.00	5.04	174.88	8.15	0.84	0.13	4.13	2.88	5.28	0.998
LAI	2019	3.44	0.13	3.39	0.29	0.61	0.57	0.20	-0.05	0.23	0.991
	2020	2.95	0.38	2.83	0.50	0.85	0.23	0.19	-0.12	0.28	0.983
Plant height	2019	1.75	0.18	1.81	0.35	0.70	0.04	0.26	0.23	0.33	0.910
	2020	1.67	0.19	1.68	0.41	0.84	0.99	0.20	0.00	0.25	0.947
SCY	2019	2957	470	2905	360	0.86	0.57	204	-52	237	0.986
	2020	2878	405	2917	441	0.83	0.67	207	39	238	0.983
ABG	2019	1598	268	1680	250	0.90	0.09	109	82	137	0.984
	2020	1810	278	1864	244	0.42	0.61	234	53	269	0.958

anthesis was satisfactory simulated by the model. A close match between observed and simulated values were found (Table 5). the mean observed days taken to anthesis were 69.38 ± 5.01 and 68.00 ± 4.34 for 2019 and 2020 respectively. Whereas, simulated days ranged from 67.75 ± 3.33 in 2019 and 67.00 ± 3.82 in 2020. MBE was 2.38 for 2019 and -1.00 for 2020. However, RMSE for 2019 was 3.14 and for 2020 the value was 1.73. The d-stat value was 0.995 and 0.999 in 2019 and 2020 respectively which was closer to 1 indicating a good agreement between observed and simulated values. During 2019 and 2020, observed days taken to first boll day were 88.50 and as 85.00 with SD of ± 4.81 and 3.51 respectively. The corresponding simulated values were 87.00 ± 5.24 and 85.13 ± 6.66 for 2019 and 2020. However, MAE value was 1.75 for 2019 and 3.38 for 2020. The RMSE of 2.00 and 3.69 has been observed for 2019 and 2020, respectively. A d-stat value close to unity (i.e., 0.999 for 2019 and 0.996 for 2020) confirmed fair simulation of first boll day by DSSATCROPGRO-cotton model. The observed and simulated physiological maturity revealed that crop maturity was observed at 177.25 ± 6.82 day for 2019 and 172.00 ± 5.04 day for 2020. For simulation of physiological maturity MAE was 3.00-4.13, RMSE was 3.94-5.28 and d-stat value was 0.999 and 0.998 in both years. There was good degree of association between simulated and observed days to physiological maturity affected by different N and irrigation regimes. Similarly, Cammarano *et al.*

2012 also simulated the days to anthesis, maturity of cotton under deficit irrigation with CROPGRO-Cotton model having the RMSE of 2 days for anthesis and 3.6 days for maturity.

Evaluation of model for crop growth and development

The observed and simulated LAI for 2019 and 2020 has been presented in Fig. 1. During 2019 and 2020, the value for mean observed LAI was 3.44 ± 0.13 and 2.95 ± 0.38 , whereas the simulated LAI was 3.39 ± 0.29 and 2.83 ± 0.50 during 2019 and 2020. The index of agreement ranged from 0.991-0.983. The mean observed value for plant height was 1.75 ± 0.18 during 2019 and 1.67 ± 0.19 during 2020 with simulated values of 1.81 ± 0.35 and 1.68 ± 0.41 during respective years. Lesser RMSE (0.25-0.33) and higher d-stat (0.910-0.947) indicated a close match between observed and simulated values for the plant height. The observed seed cotton yield under different treatments varied from 2957 ± 470 and 2878 ± 405 kg/ha during 2019 and 2020 respectively. While the simulated seed cotton yield was 2905 ± 360 kg/ha for 2019 and 2917 ± 441 kg/ha for 2020 with a MAE ranging from 204 to 207 and RMSE ranging from 237-238. However, d-stat value was 0.986 and 0.983. The results revealed that mean observed biomass was 1598 ± 268 kg/ha during 2019 and 1810 ± 278 kg/ha during 2020. Whereas, mean simulated biomass during 2019 was

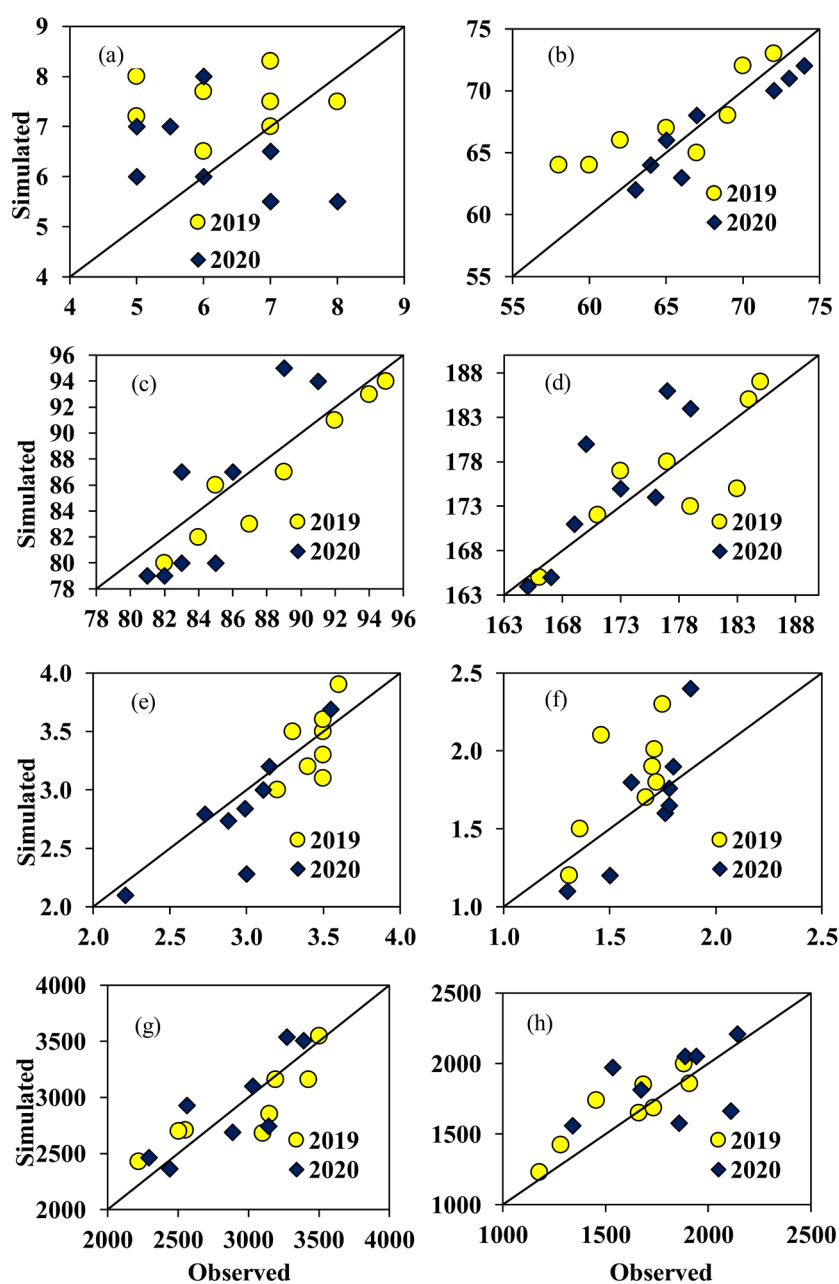


Fig. 1. Observed and simulated Emergence (a) Anthesis (b) First boll day (c) Physiological maturity (d) Leaf area index (e) Plant height (f) Seed cotton yield (g) and Above ground biomass (h) during 2019 and 2020.

1680±250 kg/ha and during 2020 it was 1864±244 kg/ha. The MAE (109-234), MBE (78-54) and RMSE (137-269) indicated that model overestimated the biomass. The value of d-stat was 0.984 during 2019

and 0.958 during 2020. Anupali *et al.* 2016 reviewed the use of CROPGRO-Cotton model under different water regimes. While simulating the yield, leaf area index and biomass, they reported error of 14%, 21%

and 12% respectively under rainfed condition and 8%, 15% and 16% respectively under irrigated conditions respectively. Kothari *et al.* 2019 used DSSAT model to simulate the yield of cotton and reported average percent error of 3.4 % during the calibration and 10.5 % during evaluation respectively. So, the results of present study clearly confirmed that CROPGRO-cotton could be successfully used for evaluation of different cotton management practices.

CONCLUSION

Subsurface fertigation of 100% RDN along with irrigation applied at 80% ETc (I₂F₂) resulted in highest seed cotton yield (3393 kg/ha) which was higher by 32.3% than surface flood irrigated cotton (C₁). Crop water use efficiency was also increased by 10 % in I₂F₂ (80 % ETc with 100% RDN) as compared to surface flood (C₁), but it was reduced by 18% under 60% ETc with 75% fertilizer applied through subsurface drip than C₁ and apparent water use efficiency of I₂F₂ was maximum (12.26 kg/ha/m³) as compared to other studied treatments. Conversely, due to least water and fertilizer input under I₁F₁ (75 % RDN with irrigation at 60% ETc), seed cotton yield was lowered by 10.6 % as compared to surface flood irrigation (C₁). The higher d-Stat and lower RMSE, MAE, MBE indicated that DSSAT-CROPGRO-cotton model can simulate various phenological, growth and yield attributes of cotton to a satisfactory level. For better seed cotton yield, subsurface irrigation at 80 % ETc along with 100% RDN (112.5 kg N/ha) in 10 equal splits should be applied at 7 days interval starting from 30-35 days after sowing.

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