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Simulation and validation using InfoCrop model for *Rabi* sorghum crop under scarcity zone of India

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Abstract

The field data (2020-21 and 2021-22) of DFRS farm, Solapur, Maharashtra, India comprising four sowing windows in *Rabi* season i.e. S_1 - 36 MW (03-09 Sept.), S_2 - 38 MW (17-23 Sept.), S_3 - 40 MW (01-07 Oct.) and S_4 - 42 MW (15-21) and varieties (Maldandi, Mauli and Yashoda) through the field experiment laid out split plot design were used for model validation.

The simulated and observed mean number of days taken to physiological maturity both the year 2020 and 2021, the RMSE (Root Mean Square Error) values for simulations were 11.51, 12.75, 13.92 and 12.80, 14.06, 15.26 for Maldandi (V_1), Mauli (V_2) and Yashodha (V_3) respectively.

Likewise, the simulation performance of the model lowest % error range found statistically good in S_3V_1 (40 MW) (3.3 to 6.1%) followed by overall rest of the treatment.

Keywords: Info Crop model, simulated yield, phenological event, predicting sorghum yield

1. Introduction

Sorghum (*Sorghum bicolour* L. moench) is a cereal grass, native to Sub-Saharan Africa has been cultivated for centuries as a staple cereal grain (Menz *et al*., 2004) [13]. Sorghum belongs to the family Gramineae and it is a C_4 plant of tropical origin.

In India, Sorghum is cultivated over 4.10 million ha with an annual production of 4.17 million tonnes of grain with a productivity of 1018 kgha^{-1} whereas, under Maharashtra 2.17 million ha area, 1.81 million tonnes and 833 kg ha^{-1}. (Annonymous, 2018) [1].

Rabi sorghum is grown from October to February. The best time of sowing for *Rabi* sorghum is 15th October to reduce incidence of shoot fly, while irrigated sorghum can be sown up to the end of October. Early sown *Rabi* sorghum is prone to heavy shoot fly incidence.

Sowing time has an impact on sorghum growth stages. Number of days between sowing and flowering decreases as planting was delayed due to slower emergence and less rapid accumulation of heat units. Planting date affects not only the time from sowing to flowering but time from flowering to physiological maturity of grain sorghum.

The InfoCrop is a generic crop growth model that can simulate the effects of weather, soil, agronomic managements (including planting, nitrogen, residue and irrigation) and major pests on crop growth and yield (Aggarwal *et al*., 2006) [2]. Different crop development and growth processes, which influence the yield, are considered in the model. InfoCrop is a simple user friendly and inputs for it are easily available. It performs well in tropical agro environments.

InfoCrop are dynamic crop yield simulation models developed to deal with the interaction among weather, crop/variety, soils and management practices besides major pest. These models have the capability of analysis of experimental data, estimate the potential yield, yield gaps and also assess the impacts of climate variability and climate change. InfoCrop model has capacity to evaluate the production of major annual crops *viz*., rice, wheat, sorghum, millet, sugarcane, chickpea, pigeon pea, cotton, maize, groundnut, potato and of course mustard and equipped with inbuilt data base of Indian soils. The InfoCrop models have the capability of analysis of experimental data, estimate the potential yield, yield gaps and also assess the impacts of climate variability and climate change. These models efficiently work for management optimization and assess environmental impact study also. Thus, these models are most versatile and have many agricultural applications used for decision support system for Agro-technology transfer.

22. Materials and Method

1. Location of the Experimental Site

The field experiment was conducted at Mulegaon Agricultural Farm, Zonal Agricultural Research Station, Solapur during rabi season 2020-21 and 2021-22. The geographical location of the site (Solapur) was 170 41'N, latitude; 750 56'E, longitude and 483.6 m above mean sea level (MSL). The soil is medium black calcareous having depth of about 90 cm. The average annual rainfall of Solapur is 545 mm.

2.2 Soil

Experimental field was uniform and levelled. The soil was moderately well drained having depth of 60 cm. In order to study the physical and chemical properties of soil, the soil samples from 0-30 cm depth at 10 different randomly selected locations were collected from the experimental area before laying out the experiment. The composite sample was analyzed for physical and chemical properties of soil and are presented in Table 2.1 along with analytical methods used. The soil of experimental site was clayey in texture. The chemical composition according to criteria laid by Mohr *et al.* (1965) indicated that the soil was low in available nitrogen (128 kg ha-^{1}), medium in available phosphorous (14 kg ha^{-1}) and very high in potassium (399 kg ha^{-1}). The soil was moderately acidic in reaction (pH 7.6) and electrical conductivity was 0.17 dSm^{-1}. The field capacity and permanent wilting point was 310 and 150 mm, respectively with bulk density of 1.2 Mg m^{-3} (Table 2.1).

2.3 Location and Climate

The Mulegaon Agricultural Farm, Zonal Agricultural Research Station, Solapur is situated in dry (Arid and Semi-arid) zone. Geographically the campus of Mulegaon Agricultural Farm is situated on 170 41' N latitude and 750 56'E longitude. The altitude is about 483.6 m above mean sea level. The maximum temperature being 40 ^{0}C or more. The highest temperature recorded was 46 ^{0}C in May during 1988. The monsoon last from June to the end of September, with moderate rainfall. The Solapur city receives an average rainfall of 545 mm per year. Winter begins in November and last until end of February, with the temperature occasionally dropping below 10 ^{0}C.

2.4 Experimental Details

The experiment was conducted in a split-plot design with four replications and twelve treatment combinations were formed considering different varieties (3) and sowing windows (4) with recommended spacing 45 cm x 20 cm during *Rab*i, 2020-21 and 2021-22.

2.5 InfoCrop Sorghum Model

InfoCrop v.2.0 model is a dynamic crop-yield simulation model. This model was developed at the Center for Application of Systems Simulation, IARI, New Delhi. Basically InfoCrop is a modular decision support system for crop modeling applications.

2.6 Input for InfoCrop v.2.0 model

The inputs required for InfoCrop v. 2.0 model is listed in Table 2.2.

3. Results and discussion

3.1 Simulation and Validation using InfoCrop model for performance of *Rabi* sorghum

One of the major goal of this study was to compare the performance of dynamic crop simulation models under Solapur conditions. Details comparison statistics of InfoCrop for days taken to 50% flowering, days taken to physiological maturity, leaf area index, test weight, grain yield and fodder yield are presented in Table 3.1 to 3.8 The overall performance of simulation was found satisfactory.

3.2 Genetic Co-efficient of sorghum for InfoCrop v.2.o model

The field experimental data collected during 2020-21 and 2021-22 during *Rabi* season for three sorghum varieties namely Maldandi, Mauli and Yashoda were used to derive genetic coefficients. The details of the coefficients derived and further used in the model for validation are given in Table 3.1

3.3 Validation of days taken to 50% flowering

The data pertaining to days to 50% flowering (days) revealed that the model simulated days to 50% flowering with reasonably slightly good accuracy for all sowing windows and varieties are presented Table 3.2 for the years 2020 and 2021.

During the year 2020, The simulated and observed mean number of days to 50% flowering was 76.5 and 69.3, 71.5 and 65.5, and 77.3 and 70.0 for the varieties Maldandi (V_1), Mauli (V_2) and Yashoda (V_3), respectively. The mean percentage error (PE) was -10.5, -9.2 and -10.4 for Maldandi (V_1), Mauli (V_2) and Yashoda (V_3), respectively across different sowing windows.

However, for the year 2021, The simulated and observed mean number of days to 50% flowering was 78.0 and 70.0, 72.9 and 66.2, and 78.8 and 70.7 for the varieties Maldandi (V_1), Mauli (V_2) and Yashoda (V_3), respectively. The mean percentage error (PE) was -11.6, -10.2 and -11.4 for Maldandi (V_1), Mauli (V_2) and Yashoda (V_3), respectively, therefore the simulation was well matched with observed values.

The test criteria for the calculated values of statistical indices *viz*., mean absolute error (MAE), mean bias error (MBE), mean square error (MSE), root mean square error (RMSE) and ability of model (R) are analysis also support that the model slightly overestimated in all the cases. According to Loague and Green (1991) [11] if RMSE is between 10-20% the simulation were good.

3.4 Validation of days taken to physiological maturity

The data on physiological maturity is presented in Table 3.3 for the years 2020 and 2021.

During the year 2020, The simulated and observed mean number of days taken to physiological maturity was 125.4 and 114.8, 124.0 and 112.0, and 125.3 and 112.0 for the varieties Maldandi (V_1), Mauli (V_2) and Yashoda (V_3), respectively. The mean percentage error (PE) was -9.2, -10.7 and -11.8 for Maldandi (V_1), Mauli (V_2) and Yashoda (V_3), respectively across different sowing windows.

However, for the year 2021, The simulated and observed mean number of days taken to physiological maturity was 127.9 and 115.9, 126.5 and 113.1, and 127.8 and 113.1 for the varieties Maldandi (V_1), Mauli (V_2) and Yashoda (V_3), respectively.

The mean percentage error (PE) was -9.2, -10.7 and -11.8 for Maldandi (V_1), Mauli (V_2) and Yashoda (V_3), respectively across different sowing windows.

However, for the year 2021, The simulated and observed mean number of days taken to physiological maturity was 127.9 and 115.9, 126.5 and 113.1, and 127.8 and 113.1 for the varieties Maldandi (V_1), Mauli (V_2) and Yashoda (V_3), respectively. The mean percentage error (PE) was -10.3, -11.8 and -12.9 for Maldandi (V_1), Mauli (V_2) and Yashoda (V_3), respectively, therefore the simulation was well matched with observed values.

Both the year 2020 and 2021, The RMSE (Root Mean Square Error) values for simulations were 11.51, 12.75, 13.92 and 12.80, 14.06, 15.26 for Maldandi (V_1), Mauli (V_2) and Yashodha (V_3) respectively, (Table 4.20). These results are in conformity with the findings of White *et al.* (2015) [15]. Harb *et al.* (2016) [10] also showed that the simulates phenophases with good RMSE values. These results are also in confirmation with the findings of Aundhkar (2001) [5] and Madiwalar (2006) [12].

The test criteria for the calculated values of statistical indices *viz*., mean absolute error (MAE), mean bias error (MBE), mean square error (MSE), root mean square error (RMSE) and ability of model (R) are analysis also support that the model slightly overestimated in all the cases. The similar result found by Arvind Kumar *et al.* (2015) [6] and Choudhary *et al*. (2014) [8].

3.5 Validation of leaf area index (LAI)

The data pertaining to days to 50% flowering (days) revealed that the model simulated leaf area index with reasonably slightly good accuracy for all sowing windows and varieties are presented and depicted in Table 3.4 for the years 2020 and 2021.

During the year 2020, The simulated and observed mean measured LAI was 1.76, 1.54, 2.27 and 1.61, 1.40, 2.09 and mean percentage error (PE) was -9.18, -9.8 and -8.75 for Maldandi (V_1), Mauli (V_2) and Yashoda (V_3) respectively.

However, for the year 2021, The simulated and observed mean measured LAI was 1.98, 1.7, 2.56 and 1.80, 1.6, 2.32 and mean percentage error (PE) was -10.0, -10.2 and -10.4 for Maldandi (V_1), Mauli (V_2) and Yashoda (V_3) respectively. For LAI performance criteria were better for variety Maldandi (M35-1) as compared to Mauli and Yashoda.

The performance of model in term of simulation of LAI. Model simulated LAI matches well measured LAI and seems to be performed satisfactory in both the seasons. The RMSE of LAI prediction was of the order of 0.16, 0.14, 0.20 and 0.19, 0.17, 0.26 in respect of varieties Maldandi (V_1), Mauli (V_2) and Yashoda are also support that the model slightly overestimated in all the cases. The similar result found by Dhakar *et al.* (2019) [9] and the result of phenological stages simulated by infocrop model are supported by Singh *et al.* (1994) [16], Akula (2003) [3], Soler *et al.* (2007) [17] and Atteri *et al*. (1999) [4].

3.6 Validation of accumulation of dry matter

The data on accumulation of dry matter is presented in Table 3.5 for the years 2020 and 2021.

During the year 2020, The simulated and observed mean measured accumulation of dry matter was 177.9, 161.9, 227.9 and 164.1, 146.3, 204.5 whereas mean percentage error (PE) was -8.4, -10.7 and -11.4 for varieties Maldandi (V_1), Mauli (V_2) and Yashoda (V_3) respectively.

However, for the year 2021, The simulated and observed mean measured accumulation of dry matter was 197.8, 174.5, 247.3 and 178.1, 158.5, 222.6 whereas mean percentage error (PE) was -11.1, -10.1 and -11.1 for Maldandi (V_1), Mauli (V_2) and Yashoda (V_3) respectively. For LAI performance criteria were better for variety Maldandi (M35-1) as compared to Mauli and Yashoda.

Measured and model simulated accumulation dry matter showed a good agreement and estimated errors were within the acceptable range. Therefore the simulation was well matched with observed values.

Both the year 2020 and 2021, The RMSE (Root Mean Square Error) simulated values for were 14.8, 17.5, 25.3 and 20.3, 16.5, 26.2 for Maldandi (V_1), Mauli (V_2) and Yashoda (V_3) respectively. (Table 4.22).

According to Dakhar *et al.* (2019) [9] InfoCrop utilizes the radiation use efficiency (RUE) based approach for dry matter production. Maximum RUE (RUEMAX) is input in the model as a function of crop / cultivar. The RUEMAX of plant is affected by abiotic (temperature, CO_2, nitrogen stress and water stress) and biotic factors. Water stress reduces RUE almost in proportion to severity.

The test criteria for the calculated values of statistical indices *viz*., mean absolute error (MAE), mean bias error (MBE), mean square error (MSE), root mean square error (RMSE) and ability of model (R) are analysis also support that the model slightly overestimated in all the cases. These results are in conformity with the findings of Kumar *et al.* (2017) [7].

3.7 Validation of test weight (1000 grain weight (g))

The data presented on test weight (g) is presented in Table 3.6 for the years 2020 and 2021. During the year 2020, The simulated and observed mean measured test weight (g) was 38.5, 37.1, 48.6 and 35.1, 33.4, 44.7 whereas mean percentage error (PE) was -9.6, -10.9 and -8.6 for varieties Maldandi (V_1), Mauli (V_2) and Yashoda (V_3) respectively.

In case of 2021, The simulated and observed mean measured test weight (g) was 39.0, 37.4, 49.5 and 35.8, 34.1, 45.6 whereas mean percentage error (PE) was -8.8, -9.7 and -8.7 for Maldandi (V_1), Mauli (V_2) and Yashoda (V_3) respectively. For overall performance criteria were better for variety Maldandi (M35-1) as compared to Mauli and Yashoda.

Among both the year 2020 and 2021, the evaluation of MAE (mean absolute error) and MBE (mean bias error) was found higher for varieties Yashoda followed by Mauli and Maldandi respectively, but variety Yashoda holds higher RMSE (3.9 and 4.0) as compared to Mauli (3.8 and 3.5) and Maldandi (3.5 and 3.3). The overall performance of test weight (g) simulation was good with accepted level for sorghum; However model slightly overestimated the test weight. (Table 4.23).

The conformity results coined by Kumar *et al.* (2017) [7].

3.8 Validation of grain yield (kg ha^{-1})

The data pertaining grain yield (kg ha^{-1}) revealed that the model simulated grain yield (kg ha^{-1}) with reasonably slightly good accuracy for all sowing windows and varieties are presented and depicted in Table 3.7 for the years 2020 and 2021.

During the year 2020, The simulated and observed mean measured grain yield (kg ha^{-1}) was 926.5, 863.3, 774.3 and 863.6, 801.4, 713.4 and mean percentage error (PE) was -7.3, -7.7 and -8.5 for Maldandi (V_1), Mauli (V_2) and Yashoda (V_3) respectively.

However, in case of 2021, The simulated and observed mean measured grain yield (kg ha^{-1}) was 982.0, 908.6, 826.4 and 919.2, 845.9, 770.1 and mean percentage error (PE) was -6.8, -7.4 and -7.3 for Maldandi (V_1), Mauli (V_2) and Yashoda (V_3) respectively. For grain yield (kg ha^{-1}) performance criteria were better for variety Maldandi (M-35-1) as compared to Mauli and Yashoda.

Both the crop season 2020 and 2021, overall the test criteria of grain yield (g) MAE, MSE, RMSE and PE for all the varieties suggested model performance was better for Maldandi (V_1) as compared to Mauli (V_2) and Yashoda (V_3) respectively. however, model slightly overestimated the grain yield in all cases. (Table 4.24).

The result simulated by infocrop model are supported by Choudhary *et al*. (2014) [8].

3.9 Validation of fodder yield (kg ha^{-1})

The data pertaining to fodder yield (kg ha^{-1}) revealed that the model simulated fodder yield (kg ha^{-1}) with reasonably slightly good accuracy for all sowing windows and varieties are presented and depicted in Table 3.8 for the years 2020 and 2021.

For the year 2020, The simulated and observed mean measured fodder yield (kg ha^{-1}) was 1956.7, 1775.4, 1608.1 and 1813.5, 1634.1, 1486.2 kg ha^{-1} and mean percentage error (PE) was -7.9, -8.6, and -8.2 for Maldandi (V_1), Mauli (V_2) and Yashoda (V_3) respectively.

However, during year 2021, The simulated and observed mean measured fodder yield (kg ha^{-1}) was 2046.8, 1766.7, 1687.4 and 1907.4, 1642.4, 1578.6 and mean percentage error (PE) was -7.3, -7.6 and -6.9 for Maldandi (V_1), Mauli (V_2) and Yashoda (V_3) respectively. For fodder yield (kg ha^{-1}) performance criteria were better for variety Maldandi (M35-1) as compared to Mauli and Yashoda.

The performance of model in term of simulation of fodder yield (kg ha^{-1}). Model simulated fodder yield (kg ha^{-1}) matches well measured fodder yield (kg ha^{-1}) and seems to be performed satisfactory in both the seasons. The RMSE of fodder yield (kg ha^{-1}) prediction was of the order of 148.8, 146.4, 123.9 and 145.0, 127.9, 111.4 in respect of varieties Maldandi (V_1), Mauli (V_2) and Yashoda are also support that the model slightly overestimated in all the cases.

The similar result found by Choudhary *et al.* (2014) [8].

Table 1: Initial physiochemical properties of soil

Sr. No.	Particulars	Results	Method adopted	Reference
A.	**Physical composition**			
1.	Sand (%)	20.82	International pipette method	Piper (1966) [18]
2.	Silt (%)	20.17	International pipette method	Piper (1966) [18]
3.	Clay (%)	58.97	International pipette method	Piper (1966) [18]
4.	Textural class	Clay loam		
5.	Bulk density (Mg m^{-3})	1.2	Core sampler	Richards (1968) [19]
B	**Chemical composition**			
1	Organic carbon (%)	0.35	Walkley and Black Rapid titration method	Allison (1975)
2	Available N (kg ha^{-1})	128	Alkaline $KMNO_4$ Method	Subbaiah and Asija (1956)
3	Available P_2O_5 (kg ha^{-1})	14	0.5 N $NaHCO_3$ Ascorbic acid	Olsen and Dean (1965) [20]
4	Available K_2O (kg ha^{-1})	399	Normal NH_4 OAC flame photometer	Knudsen *et al.* (1982) [21]
5	Soil pH (1: 2.5 soil water suspension)	7.6	Potentiometric	Jackson (1973) [22]
6	Electrical conductivity (dSm^{-1})	0.17	Conductometric	Jackson (1973) [22]
C	**Soil moisture content**			
1	Field capacity (mm)	310	Pressure plate apparatus	Richards (1968) [19]
2	Permanent wilting point (mm)	150	Pressure plate apparatus	Richards (1968) [19]

Table 2: List of inputs required for InfoCrop model v.2.0

Input variables	Acronyms Unit	Unit
Site Data		
Latitude	LAT	Degree
Longitude	Long	Degree
Altitude	Alt	Meter
Daily weather data		
Date/year	YYYY or dd-mm-yy or dd-mm-yyyy or dd-mon-yy	--
Station number	--	--
Julian days	JD	Days
Solar radiation	RDD	KJ m^{-2}
Maximum temperature	TMAX	^{0}C
Minimum temperature	TMIN	^{0}C
Vapour pressure	VP	K Pa
Wind Speed	WDST	M sec^{-1}
Rainfall	TRAIN	Mm
Relative humidity morning	RHMIN	%
Soil texture/district master parameters		
pH of soil	PHFAC	
Electrical conductivity	EC	ds/m (0 to 1)
Slope	SLOPE	%
Thickness of layer	TKL	Mm
Sand content	SAND	%
Silt content	SILT	%
Clay content	CLAY	%
Saturation fraction	WCST	0 to 1

Field capacity fraction	WCFC	0 to 1
Wilting point fraction	WCWP	0 to 1
Saturation hydraulic conductivity	KSAT mm/day	mm/day
Bulk density	BDL	Mg/m^3
Organic carbon	SOC	%
Soil moisture fraction at sowing	WCL	0.1 to 0.4
Initial soil Ammonium	NHAPL	(1 to 40 kg/ha)
Initial soil nitrate	NOAPL	(1 to 50 kg/ha)
Crop data		
Crop name	Sorghum	--
Input sowing dept.	SOWDEP	cm
Input seed rate	SEEDRT	Kg ha^{-1}
Maximum possible crop duration	--	--
Default sowing date	DATEB	Days of the year
Crop/variety management data		
Thermal time for Germination	TTGERM	degree day
Thermal time for seedling emergence to anthesis	TTVG	degree day
Thermal time for anthesis to maturity	TTGF	degree day
Base temperature	TGBD	^0C
Optimum temperature	TOPT	^0C
Maximum temperature	Tmax	^0C
Relative growth rate of Leaf area	LAII	$^0C/d$
Specific leaf area	SLAVAR	m 2 /mg
Index of greenness of leaves	--	Scale 0.8 to 1.2
Extinction coefficient of leaves at flowering	--	ha soil/ha leaf fraction
Radiation use efficiency	RUE	g/MJ/day
Root growth rate	RWRT	mm/d

Table 3: Categorization of Genetic Co-efficient of sorghum for infocrop v.2.o model

S. N.	Genetic co-efficient Description	Acronyms	Unit	Maldandi	Mauli	Yashoda
1	Thermal time for germination to emergence	TTGERM	degree day	21	19	18
2	Thermal time for seedling emergence to anthesis	TTVG	degree day	705	695.9	673.8
3	Thermal time for anthesis to maturity	TTGF	degree day	487.2	476.3	462.0
4	Specific leaf area of variety	SLAVAR	fraction	0.0016	0.0015	0.0014
5	Potential rate of growth	RGRPOT	fraction	0.82	0.81	0.79
6.	Potential rooting depth growth rate	ZRTPOT	mm/d	31	31	30
7.	Maximum number of grains per hectare	GNOMAX	grains per hectare	2717000000	2716000000	2711000000
8.	Potential weight of a grain	POTGWT	mg/grain	121	118	116

Table 4: Validation of InfoCrop model for days to 50% flowering of sorghum varieties under different sowing windows during 2020 and 2021

Treatment	Maldandi M-35-1 (V1)					
	2020			2021		
	Simulated	Observed	% Error	Simulated	Observed	% Error
S1 (36MW)	82.0	73.0	12.3	83.6	74	13.4
S2 (38MW)	81.0	75.0	8.0	82.6	76	9.1
S3 (40MW)	67.0	64.0	4.7	68.3	65	5.7
S4 (42MW)	76.0	65.0	16.9	77.5	66	18.1
Mean	76.5	69.3	-10.5	78.0	70	-11.6
SD	6.86	5.56	--	6.99	5.62	--
R	0.86			0.86		
MAE	7.25		--	8.09		--
MSE	61.75		--	75.00		--
RMSE	7.86		--	8.66		--
MBE	-7.25		--	-8.09		--
Mauli (V2)						
Treatment	2020			2021		
	Simulated	Observed	% Error	Simulated	Observed	% Error
S1 (36MW)	82.0	73.0	12.3	83.6	74	13.4
S2 (38MW)	69.0	65.0	6.2	70.4	66	7.2
S3 (40MW)	68.0	65.0	4.6	69.4	66	5.7
S4 (42MW)	67.0	59.0	13.6	68.3	60	14.7
Mean	71.5	65.5	-9.2	72.9	66.2	-10.2
SD	7.05	5.74	--	7.19	5.80	--
R	0.91		--	0.91		--
MAE	6.00		--	6.78		--

MSE	42.50		--	52.73		--
RMSE	6.52		--	7.26		--
MBE	-6.00		--	-6.78		--
Yashoda (V3)						
Treatment	**2020**			**2021**		
	Simulated	**Observed**	**% Error**	**Simulated**	**Observed**	**% Error**
S1 (36MW)	81.0	73.0	11.0	82.6	74	12.1
S2 (38MW)	85.0	80.0	6.3	86.7	81	7.3
S3 (40MW)	71.0	67.0	6.0	72.4	68	7.0
S4 (42MW)	72.0	60.0	20.0	73.4	61	21.2
Mean	77.3	70.0	-10.4	78.8	70.7	-11.4
SD	6.85	8.52	--	6.99	8.61	--
R	0.91		--	0.91		--
MAE	7.25		--	8.10		--
MSE	62.25		--	75.32		--
RMSE	7.89		--	8.68		--
MBE	-7.25		--	-8.10		--

Table 5: Validation of InfoCrop model for days to Physiological maturity of sorghum varieties under different sowing windows during 2020 and 2021

Treatment	**Maldandi M-35-1 (V1)**					
	2020			**2021**		
	Simulated	**Observed**	**% Error**	**Simulated**	**Observed**	**% Error**
S1 (36MW)	134.5	122.0	10.2	137.2	123	11.3
S2 (38MW)	128.4	121.0	6.1	131.0	122	7.2
S3 (40MW)	114.5	109.0	5.0	116.8	110	6.1
S4 (42MW)	124.0	107.0	15.9	126.5	108	17.0
Mean	125.4	114.8	-9.2	127.9	115.9	-10.3
SD	8.42	7.85		8.59	7.93	
R	0.80			0.80		
MAE	10.60		--	11.96		--
MSE	132.57		--	163.92		--
RMSE	11.51		--	12.80		--
MBE	-10.60		--	-11.96		--
Mauli (V2)						
Treatment	**2020**			**2021**		
	Simulated	**Observed**	**% Error**	**Simulated**	**Observed**	**% Error**
S1 (36MW)	136.0	122.0	11.5	138.7	123	12.6
S2 (38MW)	121.0	112.0	8.0	123.4	113	9.1
S3 (40MW)	118.0	111.0	6.3	120.4	112	7.4
S4 (42MW)	121.0	103.0	17.5	123.4	104	18.6
Mean	124.0	112.0	-10.7	126.5	113.1	-11.8
SD	8.12	7.79	--	8.29	7.87	--
R	0.81			0.81		--
MAE	12		--	13.36		--
MSE	162.50		--	197.59		--
RMSE	12.75		--	14.06		--
MBE	-12.00		--	-13.36		--
Yashoda (V3)						
Treatment	**2020**			**2021**		
	Simulated	**Observed**	**% Error**	**Simulated**	**Observed**	**% Error**
S1 (36MW)	139.0	122.0	13.9	141.8	123	15.1
S2 (38MW)	130.0	121.0	7.4	132.6	122	8.5
S3 (40MW)	118.0	109.0	8.3	120.4	110	9.3
S4 (42MW)	114.0	96.0	18.8	116.3	97	19.9
Mean	125.3	112.0	-11.8	127.8	113.1	-12.9
SD	11.4	12.2	--	11.6	12.3	--
R	0.92		--	0.92		--
MAE	13.25		--	14.64		--
MSE	193.75		--	232.79		--
RMSE	13.92		--	15.26		--
MBE	-13.25		--	-14.64		--

Table 6: Validation of InfoCrop model for Leaf area index of sorghum varieties under different sowing windows during 2020 and 2021

Treatment	Maldandi M-35-1 (V1)					
	2020			2021		
	Simulated	Observed	% Error	Simulated	Observed	% Error
S1 (36MW)	1.69	1.51	11.92	1.92	1.70	13.3
S2 (38MW)	2.01	1.87	7.49	2.24	2.09	7.4
S3 (40MW)	1.96	1.89	3.70	2.21	2.10	5.1
S4 (42MW)	1.36	1.16	17.24	1.54	1.31	17.6
Mean	1.76	1.61	-9.18	1.98	1.80	-10.0
SD	0.30	0.35	--	0.32	0.38	--
R	0.99			1.00		
MAE	0.15		--	0.18		--
MSE	0.02		--	0.03		--
RMSE	0.16		--	0.19		--
MBE	-0.15		--	-0.18		--
Mauli (V2)						
Treatment	2020			2021		
	Simulated	Observed	% Error	Simulated	Observed	% Error
S1 (36MW)	1.48	1.32	12.1	1.7	1.5	13.3
S2 (38MW)	1.48	1.36	8.8	1.7	1.5	10.5
S3 (40MW)	1.86	1.77	5.1	2.0	2.0	3.3
S4 (42MW)	1.34	1.16	15.5	1.5	1.3	16.7
Mean	1.54	1.40	-9.8	1.7	1.6	-10.2
SD	0.22	0.26	--	0.22	0.29	--
R	1.00		--	1.00		--
MAE	0.14		--	0.16		--
MSE	0.02		--	0.03		--
RMSE	0.14		--	0.17		--
MBE	-0.14		--	-0.16		--
Yashoda (V3)						
Treatment	2020			2021		
	Simulated	Observed	% Error	Simulated	Observed	% Error
S1 (36MW)	2.10	1.88	11.7	2.36	2.10	12.6
S2 (38MW)	2.39	2.25	6.2	2.69	2.50	7.8
S3 (40MW)	2.54	2.45	3.7	2.82	2.72	3.9
S4 (42MW)	2.04	1.76	15.9	2.36	1.97	20.1
Mean	2.27	2.09	-8.75	2.56	2.32	-10.4
SD	0.24	0.32	--	0.23	0.35	--
R	1.00		--	0.99		--
MAE	0.18		--	0.24		--
MSE	0.04		--	0.07		--
RMSE	0.20		--	0.26		--
MBE	-0.18		--	-0.24		--

Table 7: Validation of InfoCrop model for Accumulation of dry matter of sorghum varieties under different sowing windows during 2020 and 2021

Treatment	Maldandi M-35-1 (V1)					
	2020			2021		
	Simulated	Observed	% Error	Simulated	Observed	% Error
S1 (36MW)	172.4	156.0	10.5	189.4	169.2	11.9
S2 (38MW)	198.4	186.5	6.4	223.4	202.7	10.2
S3 (40MW)	194.5	187.8	3.6	216.4	204.2	6.0
S4 (42MW)	146.4	126.0	16.2	162.1	136.2	19.0
Mean	177.9	164.1	-8.4	197.8	178.1	-11.1
SD	23.9	29.3	--	28.0	32.3	--
R	1.00			0.99		
MAE	13.9		--	19.7		--
MSE	218.0		--	413.8		--
RMSE	14.8		--	20.3		--
MBE	-13.9		--	-19.7		--
Mauli (V2)						

Treatment	2020			2021		
	Simulated	Observed	% Error	Simulated	Observed	% Error
S1 (36MW)	158.4	139.6	13.5	168.9	151.2	11.7
S2 (38MW)	152.4	142.3	7.1	164.4	154.2	6.6
S3 (40MW)	184.4	177.9	3.7	208.4	193.3	7.8
S4 (42MW)	152.4	125.4	21.5	156.4	135.5	15.4
Mean	161.9	146.3	-10.7	174.5	158.5	-10.1
SD	15.3	22.3	--	23.2	24.5	--
R	0.95		--	0.98		--
MAE	15.6		--	16.0		--
MSE	306.6		--	271.1		--
RMSE	17.5		--	16.5		--
MBE	-15.6		--	-16.0		--
Yashoda (V3)						
Treatment	**2020**			**2021**		
	Simulated	**Observed**	**% Error**	**Simulated**	**Observed**	**% Error**
S1 (36MW)	214.4	187.0	14.6	232.4	203.3	14.3
S2 (38MW)	236.4	218.4	8.2	258.4	237.9	8.6
S3 (40MW)	246.5	235.5	4.7	269.4	256.6	5.0
S4 (42MW)	214.1	177.2	20.8	228.9	192.5	18.9
Mean	227.9	204.5	-11.4	247.3	222.6	-11.1
SD	16.2	27.1	--	19.8	29.8	--
R	0.99		--	1.00		--
MAE	23.3		--	24.7		--
MSE	639.2		--	688.7		--
RMSE	25.3		--	26.2		--
MBE	-23.3		--	-24.7		--

Table 8: Validation of InfoCrop model for Test weight (1000 grain weight (g) of sorghum varieties under different sowing windows during 2020 and 2021

Treatment	Maldandi M-35-1 (V1)					
	2020			2021		
	Simulated	Observed	% Error	Simulated	Observed	% Error
S1 (36MW)	34.5	30.9	11.6	35.4	31.5	12.3
S2 (38MW)	43.5	40.2	8.3	44.1	41.0	7.6
S3 (40MW)	44.6	42.8	4.3	45.1	43.7	3.3
S4 (42MW)	31.2	26.5	17.8	31.2	27.0	15.4
Mean	38.5	35.1	-9.6	39.0	35.8	-8.8
SD	6.62	7.67	--	6.76	7.82	--
R	1.0			1.0		
MAE	3.4		--	3.2		--
MSE	12.4		--	11.1		--
RMSE	3.5		--	3.3		--
MBE	-3.4		--	-3.2		--
Mauli (V2)						
Treatment	**2020**			**2021**		
	Simulated	**Observed**	**% Error**	**Simulated**	**Observed**	**% Error**
S1 (36MW)	34.6	30.2	14.7	34.5	30.8	12.0
S2 (38MW)	37.8	34.5	9.6	37.9	35.2	7.7
S3 (40MW)	44.5	42.5	4.8	45.1	43.3	4.2
S4 (42MW)	31.4	26.6	17.9	32.1	27.2	18.1
Mean	37.1	33.4	-10.9	37.4	34.1	-9.7
SD	5.60	6.82	--	5.66	6.93	--
R	1.00		--	1.00		--
MAE	3.6		--	3.3		--
MSE	14.4		--	12.2		--
RMSE	3.8		--	3.5		--
MBE	-3.6		--	-3.3		--
Yashoda (V3)						
Treatment	**2020**			**2021**		
	Simulated	**Observed**	**% Error**	**Simulated**	**Observed**	**% Error**
S1 (36MW)	46.5	42.0	10.8	47.4	42.8	10.9
S2 (38MW)	51.2	48.0	6.7	52.8	49.0	7.9
S3 (40MW)	52.4	49.5	5.9	53.1	50.5	5.1
S4 (42MW)	44.1	39.4	12.0	44.8	40.1	11.7
Mean	48.6	44.7	-8.6	49.5	45.6	-8.7

SD	3.91	4.82	--	4.1	4.94	--
R	1.00		--	0.99		--
MAE	3.9		--	3.9		--
MSE	15.5		--	16.3		--
RMSE	3.9		--	4.0		--
MBE	-3.9		--	-3.9		--

Table 9: Validation of InfoCrop model for Grain yield (kg ha^{-1}) of sorghum varieties under different sowing windows during 2020 and 2021

Treatment	**Maldandi M-35-1 (V1)**					
	2020			**2021**		
	Simulated	**Observed**	**% Error**	**Simulated**	**Observed**	**% Error**
S1 (36MW)	998.0	921.5	8.3	1060.0	970.6	9.2
S2 (38MW)	1062.0	994.8	6.8	1078.0	1022.2	5.5
S3 (40MW)	1088.0	1049.5	3.7	1208.0	1156.9	4.4
S4 (42MW)	558.0	488.5	14.2	582.0	527.3	10.4
Mean	926.5	863.6	-7.3	982.0	919.2	-6.8
SD	248.6	255.5	--	274.7	272.9	
R	1.00			1.00		
MAE	62.9		--	62.8		--
MSE	4171.8		--	4178.9		--
RMSE	64.6		--	64.6		--
MBE	-62.9		--	-62.8		--
Mauli (V2)						
Treatment	**2020**			**2021**		
	Simulated	**Observed**	**% Error**	**Simulated**	**Observed**	**% Error**
S1 (36MW)	911.0	823.8	10.6	978.0	904.7	8.1
S2 (38MW)	958.0	902.0	6.2	992.0	944.4	5.0
S3 (40MW)	1068.0	1036.3	3.1	1092.4	1052.8	3.8
S4 (42MW)	516.0	443.8	16.3	572.0	481.7	18.7
Mean	863.3	801.4	-7.7	908.6	845.9	-7.4
SD	240.7	254.1	--	230.1	250.7	--
R	1.00		--	1.00		--
MAE	61.8		--	62.7		--
MSE	4243.3		--	4336.9		--
RMSE	65.1		--	65.9		--
MBE	-61.8		--	-62.7		--
Yashoda (V3)						
Treatment	**2020**			**2021**		
	Simulated	**Observed**	**% Error**	**Simulated**	**Observed**	**% Error**
S1 (36MW)	882.1	794.8	11.0	848.5	777.8	9.1
S2 (38MW)	942.5	884.0	6.6	952.1	894.4	6.4
S3 (40MW)	862.4	834.5	3.3	1046.5	1005.6	4.1
S4 (42MW)	410.1	340.5	20.5	458.4	402.6	13.9
Mean	774.3	713.4	-8.5	826.4	770.1	-7.3
SD	245.2	251.3	--	258.3	262.1	--
R	1.0		--	1.0		--
MAE	60.9		--	56.3		--
MSE	4170.5		--	3280.2		--
RMSE	64.6		--	57.3		--
MBE	-60.9		--	-56.3		--

Table 10: Validation of InfoCrop model for Fodder yield (kg ha^{-1}) of sorghum varieties under different sowing windows during 2020 and 2021

Treatment	**Maldandi M-35-1 (V1)**					
	2020			**2021**		
	Simulated	**Observed**	**% Error**	**Simulated**	**Observed**	**% Error**
S1 (36MW)	2125.4	1941.6	9.47	2325.4	2141.3	8.6
S2 (38MW)	2168.9	2000.2	8.43	2146.7	1973.3	8.8
S3 (40MW)	2328.2	2249.6	3.49	2758.4	2663.5	3.6
S4 (42MW)	1204.2	1062.4	13.35	956.8	851.5	12.4
Mean	1956.7	1813.5	-7.90	2046.8	1907.4	-7.3
SD	509.2	518.2	--	770.7	762.8	--
R	1.00			1.00		
MAE	143.2		--	139.4		--
MSE	22126.6		--	21013.6		--
RMSE	148.8		--	145.0		--
MBE	-143.2		--	-139.4		--

Mauli (V2)						
Treatment	2020			2021		
	Simulated	Observed	% Error	Simulated	Observed	% Error
S1 (36MW)	1879.4	1690.4	11.2	1705.1	1543.1	10.5
S2 (38MW)	2098.4	1934.3	8.5	2198.8	2056.0	6.9
S3 (40MW)	2125.4	2035.4	4.4	2446.2	2363.6	3.5
S4 (42MW)	998.4	876.2	13.9	716.5	607.0	18.0
Mean	1775.4	1634.1	-8.6	1766.7	1642.4	-7.6
SD	529.6	525.6	--	764.9	768.8	--
R	1.00		--	1.00		--
MAE	141.3		--	124.2		--
MSE	21420.4		--	16362.2		--
RMSE	146.4		--	127.9		--
MBE	-141.3		--	-124.2		--
Yashoda (V3)						
Treatment	2020			2021		
	Simulated	Observed	% Error	Simulated	Observed	% Error
S1 (36MW)	1468.2	1333.7	10.1	1624.4	1490.2	9.0
S2 (38MW)	1897.4	1750.2	8.4	2114.5	1991.0	6.2
S3 (40MW)	2098.5	2010.6	4.4	2239.4	2169.5	3.2
S4 (42MW)	968.4	850.2	13.9	771.1	663.7	16.2
Mean	1608.1	1486.2	-8.2	1687.4	1578.6	-6.9
SD	501.0	507.4	--	666.0	674.3	--
R	1.00		--	1.00		--
MAE	121.9		--	108.8		--
MSE	15358.9		--	12420.7		--
RMSE	123.9		--	111.4		--
MBE	-121.9		--	-108.8		--

4. Conclusions

InfoCrop model was able to predict the yields of all the varieties with good RMSE values. It could be used for future climate change studies under rainfed condition. In relation to changing climate the days taken to 50% flowering, physiological maturity, leaf area index, accumulation of dry matter, 1000 grain weight, grain yield and fodder yield were satisfactorily simulated by InfoCrop model. This model proved to be valuable tools for predicting *Rabi* sorghum yield. Therefore, the validated InfoCrop can further used for applications such as prediction of crop growth, phenology and actual yield, performance of sorghum under climate change study etc. The model may also to be used to improve and evaluate the current practices of sorghum growth management to enhance sorghum production.

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