Evaluation of a crop growth model for sweet potato over a set of agro-climatic conditions in India

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A study was conducted to evaluate the wider applicability of sweet potato growth model, 'SPOTCOMS' for simulating the phenology and yield over a set of agro-climatic conditions in India. The model simulated the phenology of the crop as a function of growing degree days. The genetic coefficients required for the model were estimated from the field experiments conducted with sweet potato variety, Sree Bhadra and other local varieties at the study locations. The model simulated the yield of the sweet potato well and the statistical indices calculated between the simulated and observed yields stated the reliability of the model simulations. The agreement index (*D*-index) for Sree Bhadra ranged from 0.55 to 0.99, and the *D*-index for local varieties ranged from 0.51 to 1.00. The calculated values of normalized objective function ranged from 0.01 to 0.10 for Sree Bhadra and 0.00 to 0.22 for other local varieties, and indicated better agreement of simulated and observed yields. The normalized root mean square error ranged from 0.80% to 10.40% for Sree Bhadra and 0.00% to 22.44% for other varieties, and these results suggested the wider applicability of the model with excellent to good simulations. The model also simulated dry matter distribution in tubers pertaining to different stresses such as water, nitrogen and potassium. The study revealed that the simulation model 'SPOTCOMS' can be used for simulating the yield as well as to manage the stresses during the crop growth period and to optimize best management practices for the crop cultivation irrespective of the agro-climatic conditions.

Keywords: Crop phenology, calibration, growing degree days, SPOTCOMS, simulation.

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SWEET potato is widely cultivated in tropical and subtropical areas and is considered an important part of the staple diet in many poor countries in Africa[1]. The tubers of sweet potato are rich in carbohydrate[2], vitamins[3] and proteins[1]. Despite its potential for nutritional security, the industrial value of the crop can be exploited to ensure economic security of farmers in the context of climate change. In India, sweet potato is the third most important tuber crop after potato and cassava, and it is grown in almost all states except Jammu and Kashmir, Himachal Pradesh and Sikkim[4]. Realizing the gap between potential and actual yields at farm level in different agro-climatic conditions is important. It is tedious and laborious to quantify the yield response in different field conditions and controlled experiments. Crop simulation models represent simplified crop production systems consisting of nonlinear mathematical equations to provide a systematic analysis of the crop production system[5]. By considering the significance of this tuber crop as a staple as well as nutritional food, the present study evaluated the performance of 'SPOTCOMS – Sweet Potato Computer Simulation', a growth simulation model for the growth and yield of sweet potato[6] over different agro-climatic conditions in India, to identify its wider applicability.

Study locations were selected such that they represent different agro-climatic conditions as well as the major sweet potato growing areas in India (Figure 1). The crop model 'SPOTCOMS' is the modification of the model

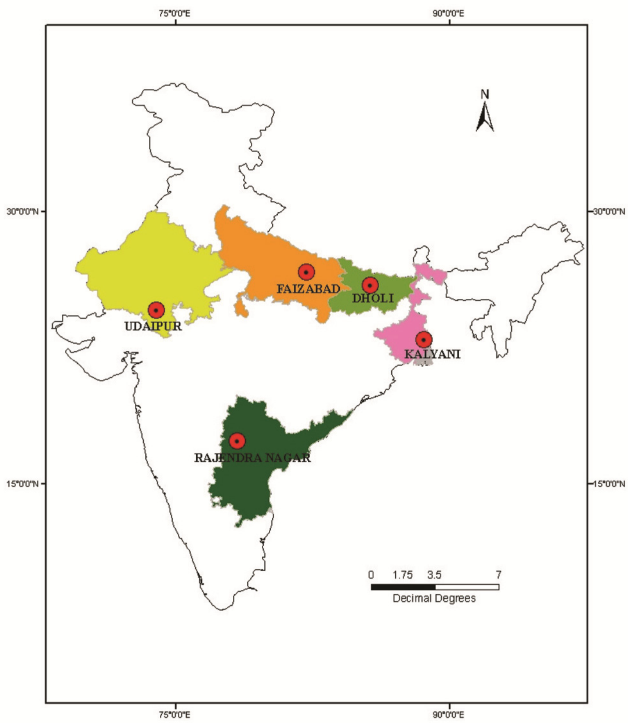

Figure 1. Map showing the study locations with different agro-climatic conditions.

Table 1. Mean values of growth and yield parameters of Sree Bhadra based on field observations

Months after planting	Vine length (cm)	Internode length (cm)	No of leaves/ plant	No of tuberous roots	Weight of tuber/ plant (g)	Dry weight above ground (g)	Dry weight below ground (g)
1	59	3	43				
2	87	4	100	5	59	28	22
3	116	4	193	5	145	44	54
4	143	4	254	5	234	41	87

Table 2. Observed values of growth parameters of local varieties of sweet potato

Months after planting	Vine length(cm)					Internode length (cm)				No. of leaves/plant			
	Dholi	Rajendra Nagar	Kalyani	Faizabad	Udaipur	Dholi	Rajendra Nagar	Kalyani	Faizabad	Dholi	Rajendra Nagar	Kalyani	Faizabad
1	58	52	7	76	40	2	3	3	4	19	91	21	52
2	84	78	19	94	67	3	4	3	4	32	187	80	93
3	99	106	42	108	122	3	3	4	4	56	302	225	241
4	114	129	72	123	160	3	3	5	4	73	409	282	409

'MADHURAM'[7], where crop phenology is predicted based on vegetative developmental days and reproductive degree days. However, in SPOTCOMS, it is predicted as a function of growing degree days (GDD) which is the accumulated daily mean temperature since planting.

$$\mathrm{GDD}_d = \sum_{i=1}^{d} T_{\mathrm{mean}_i} - d \times T_{\mathrm{base}},$$

where GDD_d is the GDD after d days of planting (DAP); T_{mean_i} is the mean temperature on ith DAP[8]. Optimum temperature and base temperature (T_{base}) for the growth of sweet potato is calculated as 25°C and 8.1°C respectively[9]. The model simulates the crop growth stages as initial, middle and third phases. The initial phase includes extensive growth of fibrous roots. Moderate growth rate of vines and extensive vine growth occur during the middle phase and this increases green leaf area and initiation of tubers. The third phase is characterized by very little growth of vines and fibrous roots, decrease in leaf area and initiation of tuber bulking. In the model, vine and tuber growth rates are calculated in terms of growing degree days and branching event is predicted as a function of number of leaves.

$$d\mathrm{VL}_i = \log\left(\frac{d\mathrm{VL}'_i + \dfrac{(\mathrm{DMV}_{i-1} - \mathrm{DMV}_{i-2})}{\mathrm{DMV}_{i-2}} \times \dfrac{(\mathrm{VL}_{i-2} + \mathrm{BR\_VL}_{i-2})}{\mathrm{BR}_{i-2}}}{2}\right)$$

where $d\mathrm{VL}_i$ is the rate of increase in vine length (VL) on ith DAP; DMV_{i-1} and DMV_{i-2} the dry matter in vines on (i–1)th and (i–2)th DAP respectively; $\mathrm{BR\_VL}_{i-2}$ the length of branches on (i–2)th DAP; VL_{i-2} the vine length of branches on (i–2)th DAP; BR_{i-2} is the number of branches on (i–2)th DAP

$$d\mathrm{VL}'_i = \frac{\mathrm{vlen} \times (\mathrm{GDD}_i - \mathrm{GDD}_{i-1})}{f}, \quad i > 1,$$

$$= \frac{\mathrm{vlen} \times \mathrm{GDD}}{f}, \quad i = 0,$$

where vlen is the parameter specific for the variety of sweet potato. Direct and diffused solar radiations are calculated separately and are used in calculating the gross photosynthesis in the model[7]. The number of leaves per plant is calculated by phenological growth rate and dry matter partitioned to the leaves. The effect of water stress on the crop growth is also computed[10]. Priestly and Taylor method is used for calculating reference evapotranspiration (ET_0). Apart from the yield estimation under water stress, the model can also assess the stress due to nitrogen and potassium deficiency. These nutrients are important inputs for increasing the number and weight of tubers. Nutrient stress on mean tuber weight is calculated using Mitscherlich's equation[11].

The crop parameters required for calibration of the model were obtained from field experiments conducted during three seasons such as 2013–2014, 2014–2015 and 2015–2016 under the All India Coordinated Research Project on Tuber Crops in five locations. In each location, a high-yielding variety of sweet potato, Sree Bhadra (ICAR-CTCRI, Thiruvanathapuram) and one local variety popular among the farmers in that location were used for

Table 3. Observed yield parameters of local varieties of sweet potato

Months after planting	No. of tuberous roots					Weight of tuber/plant (g)				Dry weight above ground (g)				Dry weight below ground (g)			
	Dholi	Rajendra Nagar	Kalyani	Faizabad	Udaipur	Dholi	Rajendra Nagar	Kalyani	Faizabad	Dholi	Rajendra Nagar	Kalyani	Faizabad	Dholi	Rajendra Nagar	Kalyani	Faizabad
2	4	5	5	3	5	47	111	72	5	10	112	0.4	17	12	100	0.2	4
3	4	5	8	4	6	208	173	110	32	26	136	0.4	18	37	156	0.3	34
4	5	5	8	4	5	312	258	208	60	36	119	1	21	58	205	0.5	60

Table 4. Derived genetic coefficients of varieties for calibrating SPOTCOMS

		Kalyani	Udaipur	Faizabad	Dholi	Rajendra Nagar
Plant parameters	Sree Bhadra*	BCSP-10	CO 3-4	NSDP-65	RS 92	RNSP 1
Phs1gdd (°C)	515.25	503.35	514.85	495.6	611.45	534.3
phs2gdd (°C)	341.16	313.35	358.2	289.5	400.35	376.75
Vlen (cm $°C^{-1}$)	0.076	0.0628	0.080	0.052	0.065	0.0644
Tgrate ($°C^{-1}$)	0.001	0.0048	0.0025	0.0032	0.002	0.0026
br_gap ($°C^{-1}$)	0.0018	0.0021	0.0015	0.0020	0.0016	0.0018
Leaf factor ($°C^{-1}$)	0.0244	0.0374	0.0230	0.0175	0.0116	0.0193
Leaf area factor (cm^2)	72.27	59.119	122.814	52.070	85.812	141.45
Leaf area (cm^2)	44.112	32.15	73.05	34.35	64.9	90.2
Row × row (cm)	60	60	60	60	60	60
Plant × plant (cm)	20	20	20	20	20	20

*Values of Sree Bhadra represent the mean values from five study centres; Phs1gdd is GDD at 4 weeks after planting under tropical conditions and 9.5 weeks under temperate conditions; phs2gdd is GDD between 4 and 7 weeks after planting under tropical conditions; Vlen is the vine length; Tgrate is the tuber growth rate; br_gap is the branch gap.

deriving crop parameters for calibrating the SPOTCOMS. A variety RS-92 was used as local trial crop in Dholi. RNSP-1, BCSP-10, NSDP-65 and CO 3-4 were used as local varieties in Rajendra Nagar, Kalyani, Faizabad and Udaipur respectively. The growth parameters of Sree Bhadra were the mean of values obtained from all the experimental locations (Table 1), whereas the local variety used in each location was different and hence the value as such was used (Tables 2 and 3). The crop coefficients for calibrating the model were derived from these observed growth and yield parameters and were listed in Table 4.

The simulated and observed yields were listed in Table 5. The model performance was evaluated using agreement index (*D*-index)[12], normalized objective function (NOF)[13] and normalized mean square error (NRMSE)[14]. The value of *D*-index ranges from 0 to 1, and closer the index value to 1, better is the agreement between the two variables that are being compared. NOF value equal to 0 indicates perfect match between observed and simulated yields. NRMSE gives a measure (%) of the relative difference of simulated and observed data. The simulation is considered excellent with a NRMSE of less than 10%, good if the value is between 10% and 20%, fair if it is more than 20% and less than 30%, and poor if the value is greater than 30% (ref. 15).

The *D*-index calculated for Sree Bhadra in the study locations ranged from 0.60 (Dholi) to 0.99 (Faizabad) indicating better model simulations with the observations. The *D*-index values of local varieties in the study locations ranged from 0.43 (Rajendra Nagar) to 1.00 (Dholi). The simulated yield of the variety RS92 in Dholi was 29.4 t ha^{-1}, same as that of the observation, which showed a *D*-index value of 1. The calculated *D*-index values in all the five locations insist the suitability of the model for simulating the crop phenology irrespective of the agro-climatic conditions. NOF values calculated for Sree Bhadra were close to zero in all locations (0.01 to 0.10). NOF value (0.00) calculated for the local variety at Dholi indicated perfect model simulation. NOF values also indicated the model suitability to simulate crop yields. The value of NRMSE for Sree Bhadra ranged from 0.80 to 10.39% (excellent to good simulations). The NRMSE values for local varieties ranged from 0.66 to 22.44 respectively.

The simulations of local varieties were found to be excellent in three locations (Dholi, Faizabad and Udaipur), good (Kalyani) and fair (Rajendra Nagar) in the other two locations. These results also revealed the wider applicability of the model for simulating the phenology and yield of sweet potato. The model also simulated total dry matter production in tubers under different stresses such as water, nitrogen and potassium (Table 6). These stress factors were analysed and used for managing during the crop growth, to obtain the potential yield. Hence,

Table 5. Model performance with respect to different criteria

Locations	Observed yield (t ha^{-1})	Simulated yield (t ha^{-1})	*D*-index	NOF	NRMSE
Sree Bhadra					
Kalyani	22.33	19.86	0.82	0.05	5.15
Udaipur	23.45	25.24	0.88	0.04	4.11
Faizabad	24.83	25.2	0.99	0.01	0.80
Dholi	19.1	22.84	0.60	0.10	10.39
Rajendra Nagar	20	20.56	0.94	0.01	1.47
Local varieties					
Kalyani	20	25.77	0.51	0.15	15.39
Udaipur	35.43	39.64	0.65	0.06	6.19
Faizabad	26.75	26.42	0.99	0.01	0.66
Dholi	29.4	29.4	1.00	0.00	0.00
Rajendra Nagar	19.3	27.38	0.43	0.22	22.44

Table 6. Simulated yields for crop varieties under different stresses

Locations	Varieties	Yield under DMTw (t ha^{-1})	Yield under DMTk (t ha^{-1})	Yield under DMTn (t ha^{-1})	Yield under DMTwk (t ha^{-1})	Yield under DMTwn (t ha^{-1})	Yield under DMTkn (t ha^{-1})	Actual yield DMTwkn (t ha^{-1})
Kalyani	Sree Bhadra	42.05	31.85	57.07	20.51	40.43	30.19	19.86
	BCSP-10	51.53	39.31	67.91	27.99	48.66	35.03	25.77
Udaipur	Sree Bhadra	53.94	27.6	49.1	27.6	49.1	25.24	25.24
	CO 3-4	85.27	42.87	79.31	42.87	79.3	39.64	39.64
Faizabad	Sree Bhadra	54.69	33.83	65.38	27.49	52.18	32.65	25.2
	NSDP-65	53.06	32.66	55.5	27.98	48.9	30.6	26.42
Dholi	Sree Bhadra	44.43	24.38	41.01	24.38	41.01	22.84	22.84
	RS 92	56.1	30.81	52.05	30.81	52.05	29.4	29.4
Rajendra Nagar	Sree Bhadra	41.58	22.88	40.46	22.52	39.67	21.5	20.56
	RNSP 1	60.74	31.76	60.42	29.36	55.96	30.14	27.38

DMT, Dry matter in tuber; DMTw, DMT due to water stress; DMTk, DMT due to potassium stress; DMTn, DMT due to nitrogen stress; DMTwk, DMT due to water and potassium stress; DMTwn, DMT due to water and nitrogen stress; DMTkn, DMT due to potassium and nitrogen stress; DMTwkn, DMT due to water, potassium and nitrogen stress.

the output of the model can be used for optimizing best management practices for sweet potato cultivation. In conclusion, SPOTCOMS can simulate growth and yield of sweet potato irrespective of the agro-climatic conditions. However, model simulations under stress conditions need to be further validated with field experiments.

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