Validation of CropSyst simulation model for direct seeded rice–wheat cropping system

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The performance and behaviour of crop models is commonly made through comparison of simulated and observed variables. The observed variables collected from field experiments conducted during 2004–05 and 2005–06 were used to study the effect of different water and nitrogen levels in direct seeded rice and wheat for rice–wheat cropping system (DSRWCS). The calibration, validation and sensitivity analysis of CropSyst model was utilized to quantify and verify the interactive effects of different water and nitrogen treatments on the productivity of direct seeded rice–wheat cropping system using the measurements from field experiments. Results showed that for direct seeded rice, the model performed well at lower levels of nitrogen (120 kg ha^{-1}), whereas at higher levels of N treatment (150 kg ha^{-1}) the predicted values underestimated the measured values. The model performed satisfactory at all levels of N in the case of wheat. Sensitivity analysis of the model for various crop parameters showed that the model is highly sensitive to the parameters like light to above biomass conversion, specific leaf area and phenological degree-days. Thus, more accuracy is required in determination of these parameters in the model. Further the root mean square error for biomass and grain yield was found to be 0.7 and 0.33 Mg ha^{-1}, which was 9% and 13% of the observed mean respectively, in direct seeded rice, whereas for wheat crop it was 0.80 and 0.33 Mg ha^{-1} respectively, which in turn was 10% and 9%, indicating that the CropSyst model is highly accurate in predicting the grain yield and above-ground biomass of the DSRWCS.

Keywords: Biomass, CropSyst, crop simulation models, nitrogen-use efficiency, rice, wheat.

CROPSYST simulation model[1], a multiyear, multicrop, daily time-step cropping system simulation model developed by Stockle *et al.*[1,2] serves as an analytical tool to study the effect of climate, soil and management on cropping system productivity and the environment. The model simulates the soil water budget, soil plant nitrogen budget, crop phenology, canopy and root growth, biomass production, crop yield, residue production and decomposition, soil erosion by water and salinity. These processes are affected by weather, soil characteristics, crop characteristics and cropping system management options, including crop rotation, cultivar selection, irrigation, nitrogen fertilization, soil and irrigation, water salinity, tillage operation and residue management.

In Central India, rice–wheat is a dominant cropping system and mostly transplanted rice is practised, but the large-scale adoption of this system had resulted in overexploitation of the groundwater resources, thus threatening the existence of agricultural productivity[3]. Also the economic factors, such as rising labour cost and increasing competition for natural resources have also enforced the need for less labour, water and land-demanding rice cultivation practices[4–9] which can be made possible by adopting the technique of growing direct seeded (DS) rice, which requires less irrigation with reduced losses due to evapotranspiration (ET) besides maintenance of soil structure beneficial for non-rice crop in rotation[5].

Rice grown in aerated soils will also tend to reduce methane emission[10]. Depending upon the system, direct seeding instead of transplanting can reduce labour requirement up to 50% (ref. 11). In rice establishment method the total amount of N fertilizer applied was higher for transplanted than for broadcast seeded rice[12]. This may be a rationale decision since high fertilizer N application increases lodging, particularly in a broadcast seeded crop with poor root establishment[13]. With the increasing popularity of broadcast seeding in Southeast Asia, it is imperative that fertilizer N management practices to be developed.

Although the CropSyst model has been used widely to evaluate the performance of several crops under different pedoclimatic and crop-water management conditions, studies on simulation of water and nitrogen balance for DS rice under rice–wheat cropping system are lacking. Therefore, the need to set up approach models for scenario analysis of cropping system models has been increasing. Thus, the present study was contemplated with the following objectives: (i) Collection of crop and soil-specific parameters from the two-year field experiments of DS rice and wheat in DSRWCS under varying water and nitrogen levels and also from the available literature. (ii) Calibration and validation of CropSyst model to quantify the interactive effect of different water and

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nitrogen treatments on the productivity of DSRWCS. (iii) Verification and sensitivity analysis of the CropSyst model using the measurements from field experiments for DSRWCS.

Materials and methods

Soil parameters

Field experiments were carried out on clay loam soils (Typic haplustept) of main block 14-B at the research farm of Indian Agricultural Research Institute (IARI), New Delhi during kharif and rabi seasons of 2004–05 and 2005–06. Soil physico-chemical properties of the experimental plot were determined up to a depth of 90 cm at an interval of 0–15, 15–30, 30–60 and 60–90 cm following standard procedures (Table 1). Soil samples from different depths were taken at an interval of one month and also at harvest stage and before sowing of each crop.

Experimental details

During the cropping seasons of kharif 2004 and Rabi 2004–05, DS rice and wheat crops were taken in their respective sequence. The experiment was conducted in a plot size of 7.5 × 6.75 m. Split plot design with three replications was used with three levels of irrigation as the main plot treatment and four levels of nitrogen as subplot treatment. Details of the treatments of each crop are given in Table 2. The experiment on DS rice and wheat was repeated during 2005–06 for validation of the CropSyst model, keeping the same levels of treatment and management practices. The recommended agronomic practices were carried out for both the crops during both the years of study.

Crop growth and yield parameters

Plant samples were taken at monthly intervals and at harvest of each crop for estimation of crop-based parameters, viz. leaf area, above-ground biomass (dry weight at 70°C) and total plant nitrogen content. Grain yield was computed from crop cutting of (1 × 1) m area at three different locations in each plot and is expressed in mega gram/ha (Mg ha^{-1}).

Weather data

Daily weather data on maximum and minimum temperature, maximum and minimum relative humidity, solar radiation, wind speed and rainfall during the crop growth period were collected from the meteorological observatory (150–200 m away from the experimental site) maintained at the Division of Agricultural Physics and Water Technology Centre, IARI, New Delhi.

Numerical experiments

Five input data files are required to run CropSyst – ⟨simulation control⟩, ⟨location⟩, ⟨soil⟩, ⟨crop⟩ and ⟨management⟩ files. The ⟨simulation control file⟩ combines the different types of input files which specify the start and ending day of simulation and the crop rotation to be simulated and sets the values of all parameters requiring initialization. The ⟨location file⟩ includes information such as latitude, ⟨weather file⟩ comprises of the code name and directories, rainfall intensity parameters, selection of ET model, etc. The ⟨soil file⟩ includes surface Cation Exchange Capacity (CEC) and pH for the estimation of ammonia volatilization. For each soil layer thickness and texture must be specified. The ⟨management file⟩ includes scheduled and automatic management events. The ⟨crop file⟩ allows a user the much needed access to a common set of parameters to represent different crop and crop cultivars. The file is structured in the following sections: phenology, morphology, growth, residue, nitrogen, harvest index, salinity tolerance and CO_2-elevation response.

The model was calibrated using the observed data on phenology, morphology, growth and harvest from the experiment conducted during 2004–05 for these cultivars in the ⟨crop⟩ file of the model. The other parameters for the ⟨crop⟩ file were taken as default with slight adjustments within the range. The crop parameters used in the model are given in Table 3.

During the first step of calibrating the Cropsyst model for DSRWCS, simulated phenological stages (degree-days) were calculated from the observed weather data and the base temperature for both the crops. Morphological parameters observed from the experiment and extracted from the literature were also adjusted in the CropSyst model. ⟨Location⟩ file was also prepared using the actually observed data for the experimental site. Harvest index (HI) parameter was calculated from the observed data (eq. (1)). Thus, the calibrated model was validated for grain yield and above-ground biomass using the crop data of DS rice (2005) and wheat (2005–06).

$$\text{HI} = \text{Yield biomass/total cumulative biomass at harvest.} \quad (1)$$

Statistical test

Statistical test was used to calculate the percentage of difference between measured and predicted values for each crop in each growing season for each treatment as follows.

Modelling efficiency (%): This is defined as a mathematical measures of how well a model simulation fits the available observations.

Table 1. Physico-chemical properties of the experimental site (direct seeded rice–wheat)

	Depth (cm)			
Soil properties	0–15	15–30	30–60	60–90
Sand (%)	35.80	35.60	58.80	49.20
Silt (%)	36.00	33.60	26.40	34.40
Clay (%)	28.20	30.80	14.80	16.40
Textural class	Clay loam	Clay loam	Sandy loam	Loamy sand
pH (1 : 2 :: soil : water)	6.82	7.25	7.25	7.30
Electrical conductivity (dS m^{-1})	0.377	0.248	0.159	0.166
Permanent wilting point (m^3 m^{-3})	0.135	0.123	0.060	0.060
Hydraulic conductivity (m day^{-1})	0.047	0.028	0.153	0.048
Field capacity (m^3 m^{-3})	0.232	0.225	0.170	0.176
Bulk density (g cm^{-3})	1.44	1.46	1.60	1.67
Organic carbon (%)	0.55	0.50	0.31	0.25
NH_4^+–N (kg N ha^{-1})	3.94	5.22	4.89	3.52
NO_3^-–N (kg N ha^{-1})	3.94	4.26	3.36	1.02

Table 2. Experimental details for direct seeded (DS) rice and wheat

Treatment	DS rice 2004	DS rice 2005	Wheat 2004–05	Wheat 2005–06
Main plot				
Maximum irrigation	Continuous flooding (W1)	Continuous Flooding (W11)	05 (W1)	05 (W11)
Medium irrigation	One-day drainage (W2)	One-day drainage (W21)	03 (W2)	03 (W21)
Minimum irrigation	Three-day drainage (W3)	Three-day drainage (W31)	02 (W3)	02 (W31)
Sub-plots				
Control	N_0PK (T1)	N_0PK (T1)	N_0PK (T1)	N_0PK (T1)
75% Nitrogen	N_{75} PK (T2)	N_{75} PK (T2)	N_{75} PK (T2)	N_{75} PK (T2)
100% Nitrogen*	N_{100} PK (T3)	N_{100} PK (T3)	N_{100} PK (T3)	N_{100} PK (T3)
150% Nitrogen	N_{150} PK (T4)	N_{150} PK (T4)	N_{150} PK (T4)	N_{150} PK (T4)

*100% Nitrogen is the recommended dose (120 kg N ha^{-1}); 100% P and K (75 kg P_2O_5 and 45 kg K_2O).

$$ME = 1 - \frac{\sum_{i=1}^{n}(O_i - S_i)^2}{\sum (O_i - \bar{O})^2},$$

where O_i and S_i represent the observed and simulated values, n represents the number of observed and simulated values used in comparison and O is the observed average

$$\bar{O} = \sum_{i=1}^{n} \frac{O_i}{n}.$$

Root mean square error (RMSE): This is a frequently used measure of the difference between values predicted by a model and those actually observed from the experiment that is being modelled. The RMSE values can be used to distinguish model performance in a calibration period with that of a validation period as well as to compare the individual model performance to that of other predictive models.

$$\text{RMSE} = \sqrt{\left(\frac{1}{n}\sum_{i=1}^{N}[O_i - S_i(b)]^2\right)}.$$

Mean absolute error (MAE): This measures the average magnitude of the errors in calibrated and validated data, without considering their direction. It measures accuracy for continuous variables.

$$\text{MAE} = \frac{\sum_{i}^{n} IO_i - S_i I}{n}.$$

Mean biased error (MBE): This is a measure of overall bias error or systematic error between the observed and the simulated parameters.

$$\text{MBE} = \frac{\sum_{i}^{n}(O_i - S_i)}{n}.$$

Sensitivity analysis

Knowledge about model uncertainty is essential for crop modelling that provides valuable information crucial for a real understanding of the model behaviour and for parameterization purposes. Models do not always behave intuitively and since parameterization errors are one of

Table 3. Crop parameters for CropSyst simulation of growth and yield of DS rice and spring wheat

Parameter	DS rice 2004	DS rice 2005	Wheat 2004–05	Wheat 2005–06
Observed parameters				
Growing degree days emergence (°C-day)	123	132	62	71
Growing degree days peak leaf area index (LAI) (°C-day)	1835	1525	800	950
Growing degree days flowering (°C-day)	1884	1547	748	947
Growing degree days maximum grain-filling (°C-day)	2062	1726	969	1084
Growing degree days maturity (°C-day)	2344	2262	1337	1441
Maximum harvest index	0.35	0.35	0.5	0.5
Maximum expected LAI	6.50	6.50	6.00	6.00
N uptake adjustment (0–2)	0.20	0.20	0.20	0.20
Maximum nitrogen concentration at emergence (kg kg^{-1})	0.06	0.06	0.07	0.07
Maximum nitrogen concentration at maturity (kg kg^{-1})	0.01	0.01	0.001	0.001
Minimum nitrogen concentration at maturity (kg kg^{-1})	0.0015	0.0015	0.0001	0.0001
Site-specific data from the literature				
Base temperature (°C)	10.00	10.00	6.00	6.00
Cut-off temperature (°C)	40.00	40.00	30.00	30.00
Optimum mean daily temperature (°C)	30.00	30.00	18.00	18.00
Maximum root depth (m)	1.50	1.50	2.00	2.00
Parameters set by calibration				
Specific leaf area (m^2 kg^{-1})	22.00	22.00	25.00	25.00
Stem/leaf partition coefficient	1.00	1.00	1.00	1.00
Leaf duration (°C-day)	700	700	1050	1050
Evapotranspiration (ET) crop coefficient	1.60	1.60	0.8	0.8
Critical canopy water potential (J kg^{-1})	–1300	–1300	–1600	–1600
Wilting canopy water potential (J kg^{-1})	–2200	–2200	–2500	–2500
Biomass/transpiration coefficient (K Pa)	7.00	7.00	7.50	7.50
Extracted from CropSyst manual				
Light to above-ground biomass conversion (g MJ^{-1})	3.00	3.00	3.50	3.50
Maximum water uptake rate (mm/day)	13.00	13.00	15.00	15.00

the primary sources of uncertainty with many models[14], sensitivity analysis was done to evaluate the response of the model to changes in input parameters and to gain an understanding of how much error could result by overestimating and underestimating the parameters values. The sensitivity analysis consist of uniformly increasing or decreasing the value of one model input parameter while keeping the value of the other parameter constant and then noting the change in biomass yield (or any other output parameter) as a result of these changes. The variation of above-ground biomass at physiological maturity, as the model parameters change, was investigated. This was chosen as an indicator because it is a synthetic representation of the culmination of many different biophysical processes. Hence, the sensitivity analysis was done for various crop input parameters over ± 5, ± 10, ± 15 and ± 20% with above-ground biomass as an output parameter to identify the input parameters to which the model is most sensitive.

Results and discussion

Calibration and validation

CropSyst calibration: The model was initialized each time prior to rice sowing in the cropping season of 2004–05. The crop parameters used for the simulation of Cropsyst are shown in Table 3. For calibrating the Cropsyst model, the parameters were adjusted for the dataset of first year 2004–05 for all levels of N-fertilizer and water treatments in DS rice and wheat for DSRWCS. The calibrated model was implemented to generate data on biomass and yield of DS rice and wheat.

CropSyst validation: After calibration of the model for DS rice 2004 and wheat 2004–05, it was validated for the next year crop 2005–06. Comparison of experiment (*O*) and simulated (*S*) results with respect to grain yield and biomass are shown in the Figures 1 and 2. Evaluation of model performance was also carried out by using different statistical tools for these comparisons in DS rice and wheat (Table 4).

In DS rice, the model performed well at lower levels of nitrogen, i.e. T1, T2 and T3 (up to 120 kg ha^{-1}), whereas the response to higher doses of nitrogen T4 (150 kg ha^{-1}) was poor for all validated parameters, viz. grain yield and biomass. This deviation of the CropSyst model at higher nitrogen levels for grain yield and biomass might be due to reduction in N losses in the form of NH_3 volatilization in DSR rice[10,12]. Also, the exchangeable NH_4^+–N depletion was faster in DS rice because of its higher growth rate during the vegetative stage, which tends to increase N uptake[15]. These characteristic of DS rice might not have

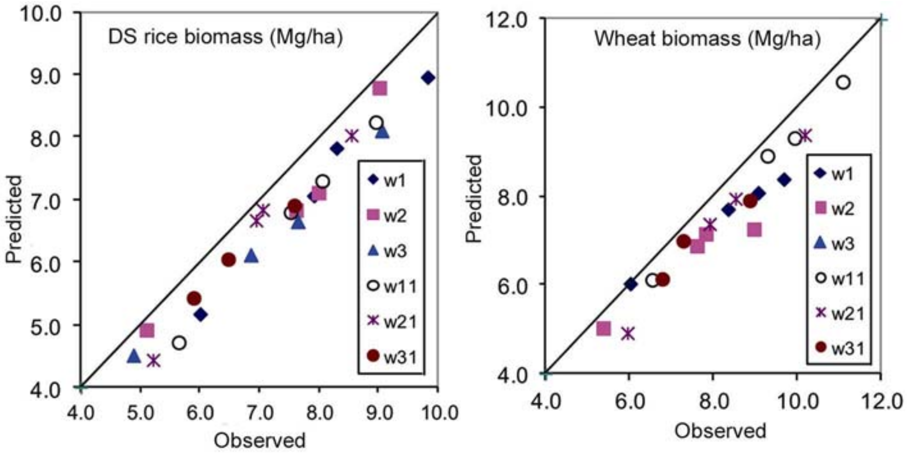

Figure 1. Observed and predicted biomass (Mg ha^{-1}) in direct seeded (DS) rice 2004 and 2005, and wheat 2004–05 and 2005–06 under maximum (w1, w11), medium (w2, w21) and limited (w3, w31) irrigation for all nitrogen treatments.

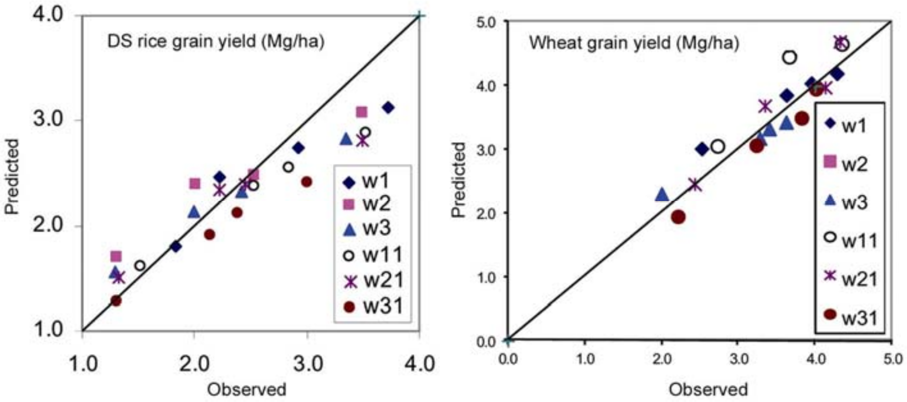

Figure 2. Observed and predicted grain yield (Mg ha^{-1}) in DS rice 2004 and 2005 and wheat 2004–05 and 2005–06 under maximum (w1, w11), medium (w2, w21) and limited (w3, w31) irrigation for all nitrogen treatments.

Table 4. Statistical summary comparing observed data with simulated values for DS rice–wheat cropping system using CropSyst simulation model

Crop	Parameter	*N*	Observed mean	Predicted mean	MAE (Mg ha^{-1})	R^2	RMSE (Mg ha^{-1})	ME (%)	MBE (Mg ha^{-1})
Rice	Biomass (Mg ha^{-1})	24	7.20	6.55	0.65	0.97	0.70	53.0	0.65
	Grain yield (Mg ha^{-1})	24	2.41	2.29	0.27	0.90	0.33	80.2	0.12
Wheat	Biomass (Mg ha^{-1})	24	7.82	7.11	0.71	0.95	0.80	76.2	0.70
	Grain yield (Mg ha^{-1})	24	3.46	3.55	0.26	0.84	0.33	89.5	–0.10

N, No. of observations; R^2, Pearson's correlation coefficient; RMSE, Root mean square error; MAE, Mean absolute error; MBE, Mean biased error; ME, Modelling efficiency.

been incorporated in the CropSyst model due to which the predicted value underestimated the observed value at higher N levels, i.e. 150 kg/ha for both the estimated parameters, viz. grain yield and biomass. However, the model performance was satisfactory at all levels of nitrogen in the case of wheat (Figures 1 and 2).

The model responded well to different levels of irrigation with significant R^2 values between those observed and predicted. In pooled statistical analysis, the R^2 values were lower for grain yield than biomass (Table 4). Also, other statistical tools, viz. RMSE, MAE and MBE were much higher for biomass than grain yield and model efficiency was higher for grain yield than biomass. Thus, the model is potentially more accurate at predicting grain yield than biomass.

RMSE for biomass and grain yield was 0.7 and 0.33 Mg ha^{-1} which was 9% and 13% of the observed mean respectively in DS rice, whereas for wheat crop it was 0.80 and 0.33 Mg ha^{-1}, which in turn was 10% and 9% respectively. These low values of RMSE indicated that the CropSyst model is accurate at predicting yield and biomass for DS rice and wheat crops. Also, it had been reported that RMSE for spring wheat is 7, 13 and 13% of the observed mean for ET, grain yield and above-ground biomass respectively[16,17]. Also, the higher R^2 values for biomass and yield indicate that the model is fit for predicting these two initial parameters[18]. Singh *et al.*[19] also indicated that the CropSyst model is more appropriate than CERES-Wheat in predicting growth and yield of wheat under different N and irrigation application situations, where RMSE was 0.36 t ha^{-1} compared to 0.63 t ha^{-1}.

The results obtained from running the model for DS rice and wheat under both growing seasons implied that the model can be used in simulating DS rice and wheat crops under varied situations with high accuracy and efficiency. Although the above situation provides only a limited evaluation of the model, it should be further tested for more data with varied treatments in different locations and years, if available.

Sensitivity analysis

To test the CropSyst model sensitivity to several crop input parameters, sensitivity analysis was done by varying the values of crop input parameters by ± 5, ± 10, ± 15 and ± 20% to find the per cent change in predicted outputs (viz. biomass yield and other parameters). The variation of above-ground biomass at physiological maturity as model parameter change was investigated; this was chosen being a synthetic representation of the culmination of different biophysical processes[20]. For CropSyst, the simulation of above-ground biomass was mainly based on the efficiency of the conversion of transpired water into biomass and radiation use efficiency. Above-ground biomass was also a product of all crop parameters, acting in conjunction with each other. The results are presented in Table 5 and Figure 3. No change was observed in biomass yield upon sensitivity analysis for crop input parameters, i.e. maximum harvest index, cut-off temperature, and maximum and minimum N concentration at maturity (kg kg^{-1}).

The model was found to be highly sensitive to light to above-ground biomass conversion (g MJ^{-1}), specific leaf area (m^2 kg^{-1}) and phenological degree-days and accounted for more than ± 10% variation in biomass yield (Table 5). Among these, specific leaf area almost had the same effect on per cent change in biomass on both the positive and negative side. But the effect of light to above-ground biomass conversion was high on the negative side than on the positive side, and the effect of phenological degree-days was much higher towards the negative side and less towards the positive side. Thus, light to above-ground biomass conversion and phenological degree-days need more accuracy in determination. Specific leaf area corresponds to leaf area per unit of leaf biomass. It is used to determine the amount of green area index produced in a day. Biomass yield increases with increase in specific leaf area and vice versa. With decrease in phenological degree-days, biomass yield decreases because the leaf area decreases due to which the yield decreases. So the model is also sensitive to this parameter.

Biomass variation of ± 5–10% was due to the base temperature, optimum mean daily temperature, leaf duration, maximum N concentration at emergence and biomass/transpiration coefficient (Table 5). Biomass/transpiration coefficient represents the above-ground biomass production per metre of transpiration under given condition of atmospheric vapour density deficit. Crop growth occurs during active growth until maturity and only when ET model has determined potential transpiration. The parameters effective in CropSyst are those closely related to the energy use, including T_{base} and radiation use efficiency which affects temperature-based correction factor of radiation-dependent growth.

Interpretation of results and discussion

In the model, above-ground crop growth is represented in terms of above-ground biomass accumulation, which

Table 5. Percentage change in biomass of the various crop input parameters by varying the parameters in CropSyst model

Change in biomass (%)	Crop input parameter
Maximum harvest index	
0	Cut-off temperature
	Maximum *N* concentration at maturity (kg kg^{-1})
	Minimum *N* concentration at maturity (kg kg^{-1})
± 0–5	Maximum rooting depth (m)
	Maximum expected leaf area index (LAI)
	Stem/leaf partition coefficient
	ET crop coefficient
	Maximum water uptake rate (mm/day)
	Critical canopy water potential (J kg^{-1})
	Wilting canopy water potential (J kg^{-1})
	N uptake adjustments (0–2)
± 5–10	Base temperature (°C)
	Optimum mean daily temperature (°C)
	Leaf duration (°C-day)
	Maximum N concentration at emergence
	Biomass/transpiration coefficient (KPa)
± > 10	Light to above-ground biomass conversion (g MJ^{-1})
	Specific leaf area (m^2 kg^{-1})
	Phenological degree days

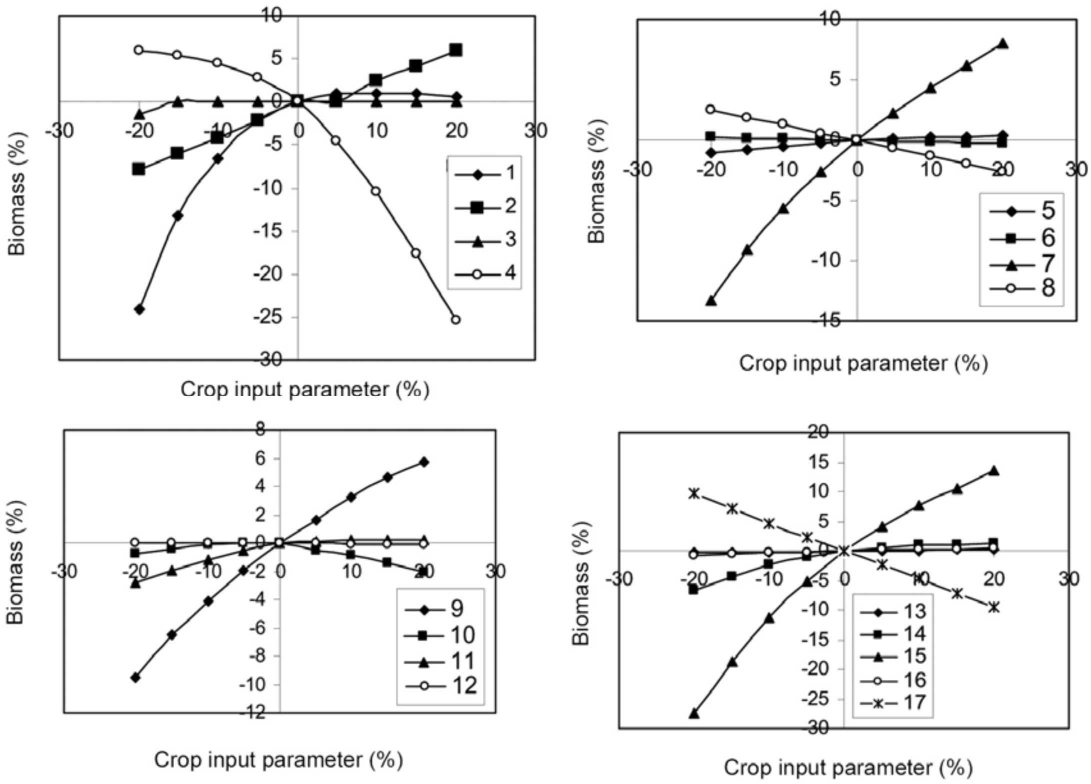

Figure 3. Schematic representation of the sensitivity analysis of various input parameters used in CropSyst model. 1, Phenology degree-days (°C-days); 2, Base temperature (°C-days); 3, Cut-off temperature (°C-days); 4, Optimum mean daily temperature (°C-days); 5, Maximum rooting depth (m); 6, Maximum expected LAI; 7, Specific leaf area (m^2 kg^{-1}); 8, Stem/leaf partition coefficient; 9, Leaf duration (°C-days); 10, ET crop coefficient; 11, Maximum water uptake rate (mm/day); 12, Critical canopy water potential (J kg^{-1}); 13, Wilting canopy water potential (J kg^{-1}); 14, Biomass/transpiration coefficient (kPa); 15, Light to above-ground biomass conversion (g MJ^{-1}); 16, Nitrogen uptake adjustment (0–2); 17, Maximum nitrogen concentration at emergence (kg kg^{-1}).

depends on intercepted radiation, transpiration (water-dependent) and plant nitrogen uptake (nitrogen-dependent). Each of these factors is capable of limiting plant growth. The optimum temperature for growth is the temperature above which growth will not be affected. The optimum temperature also indirectly affects biomass accumulation. Also, the yield decreases with increase in optimum temperature and vice versa. The rest of the parameters were found to affect the biomass production by only ± 0–5%, as is evident from Table 5. Also, ET crop coefficient and stem leaf partition coefficient had more effect on biomass production than the other coefficients/parameters. Yield decreases with increase in ET crop coefficient at full canopy and vice versa. Wilting canopy water potential is the leaf water potential at the point when the crop can no longer extract water from the soil and is used in the calculation of actual transpiration in the model. Maximum water uptake is the water uptake by the fully developed green crop, completely covering the ground unstressed, fully watered, with unrestricted root growth and under environmental conditions providing large atmospheric demand. Stem/leaf partition coefficient adjusts the proportion of cumulative biomass that is partitioned to green leaf area production as the crop accumulates biomass during the active growth stage. It is used to determine the amount of green area index produced in a day. Also the yield decreases with increase in critical canopy water potential, stem/leaf partition coefficient and vice versa.

Thus, CropSyst introduces several conceptual simplifications and works with a smaller set of input parameters. The core of the simulation engine for crop growth is based on two simple functions for radiation and transpiration-dependent growth[21], which rely on two input parameters, i.e. the light-to-biomass conversion coefficient (LtBC, as kg MJ^{-1}), and the water-to biomass conversion ratio (BTR, as kg m^{-3} kPa). The approach to dry matter partitioning is also simple and based on one empirical equation with two main input parameters – the leaf area/plant biomass ratio at the early growth stages (LAR, as m^2 leaves kg^{-1} plant) and the stem–leaf partition coefficient (SLP, as m^2 kg^{-1}), that accounts for the sharp decline of LAR as biomass accumulates over time[21]. On the other hand, dry matter partitioning to commercial yield is simply simulated by multiplying final accumulated biomass by the harvest index, eventually corrected by water stress during flowering and fruit ripening. It has been shown that LtBC, BTR, LAR and SLP, together with other phenological parameters, strongly affect simulation results and thus must be chosen with care[22–24].

Conclusions

The present study shows that despite the scientific shortcuts introduced by CropSyst, by following a careful parameterization, the practical value of this model may hold good in simulating DSRWCS when used for management and legislative purposes. The Cropsyst model simulated the biomass and grain yield reasonably well for DS rice and wheat in DSRWCS. The model underestimated the biomass and grain yield at higher levels of N (150 kg ha^{-1}) for DS rice, but simulated well at all levels of N in the case of wheat. The model is sensitive to parameters like light to above-ground biomass conversion, specific leaf area and phenological degree-days and is not sensitive to parameters like maximum harvest index, cut-off temperature, and maximum and minimum N concentration at maturity for estimating biomass and yield for DSRWCS. It is, therefore, desirable that such crop rotations should be selected which may result into maximum conversion of inputs into economic outputs and simulation using CropSyst or any other crop growth simulation model should be adopted to help the planners in achieving these goals with least monetory requirements at proper time.

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