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Integrated effect of water regimes and nitrogen levels on productivity of transplanted rice (*Oryza sativa*) and wheat (*Triticum aestivum*) under rice-wheat cropping system: Field and simulation study

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ABSTRACT

Field experiment was consecutively conducted for two years on deep alluvial clay loam soil (*Typic haplustept*) with three levels of water regimes and four levels of nitrogen in rice-wheat cropping system. Integrated effect of water and nitrogen levels depicted the rice and wheat grain yield of 3.55 and 3.41 Mg/ha respectively. Individually, grain yield increased by 104.9 and 70.3% respectively for rice and wheat with increasing N levels from 0-180 kg/ha. A reduction of 9.6 and 19.7% in grain yield was observed with change in treatment of water regimes from W_1 to W_2 and W_1 to W_3 in rice. The corresponding values for wheat were 6.3 and 13.7%, respectively. The simulation study, carried out by calibrating and validating the CropSyst model, showed the simulation yields were in agreement with observed yields as was evident by high correlation coefficient (0.87 – 0.96) and modeling efficiency (0.79 – 0.95) at all water regimes and nitrogen levels for biomass and grain yield. Also, the root mean square error (RMSE) for biomass and grain yield was 5 and 9% of the observed mean in rice which was 3 and 18% for wheat indicating that the model is accurate in predicting these two initial parameters. The model was tested for accuracy in determining the crop parameters by conducting sensitivity analysis which depicted that the above ground biomass conversion, optimum mean daily temperature and phenological degree days needs more accuracy in simulation. Pooled experimental data of the two years showed that substantial water saving can be done but the yield was reduced by 9.6 and 19.7% in rice and 6.3 and 13.7% in case of wheat which can be neglected at the time of rising global water stress.

Key words: Calibration, CropSyst model, Nitrogen, Simulation, Validation, Water regimes treatments

The Indo-Gangetic Plain (IGP) occupies nearly 15% of the total geographical area of India (Pal *et al*. 2009). Rice (*Oryza sativa*) and wheat (*Triticum aestivum*) is the important predominant cropping system of Indo-Gangatic Plains in India. Area under rice crop in IGP of India is 10 million ha (Jalota *et al*. 2009). The rapid spread of rice-wheat system in IGP has mainly been attributed to better adoptability, availability of high yielding varieties and mechanization of the crops and also due to favourable climatic conditions.

In this semi-arid subtropical region, rice is mainly grown on coarse to fine textured puddled soils during *kharif* and summer seasons by transplanting 21–30 days old seedlings. Due to extreme hot weather during May-June, non-availability and irregular supply of water through canals, transplanting is staggered from the month of May to end of June or at the onset of rains so as to avoid extra burden on ground water resources for meeting the crop water requirement (Chahal *et al*. 2007). This erratic use of ground water resources resulted in decline of water table at high rate of 0.065 m/year from 1998 – 2005 (Singh 2006).

With a growing global population, there is need to ensure crop production and food quality (Borloug 2003) and nitrogen is the major plant nutrient extensively used in irrigated agriculture in IGP of India (Aulakh and Malhi 2005, Ryan *et al*. 2009). Soil, plant and climatic conditions directly affect the N fertilizer use efficiency that is generally low in most agricultural systems (Ma *et al*. 2009) and its determination is very important for improving the N use efficiency.

The decline in groundwater resources threatens the maintenance of agricultural productivity through water saving (Kijne *et al*. 2003, Chahal *et al*. 2007) by shifting the transplanting date to the period having lower evaporative demand and dry sieving by reduction in irrigation water applied by submergence/non-submergence technology or intermittent wetting and drying from the surface (Sandhu *et al*. 1980, Singh *et al*. 1996, Tabbal *et al*. 2002).

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Scheduling irrigation and N budgets to save irrigation water and improve N use efficiency, without loss in the yield has been suggested by Kukal *et al.* (2005) and Singh *et al.* (2013). It saves water and improved N use efficiency can be achieved by simultaneous field and modeling approaches to get conclusive results for the future use by the researchers (Chahal *et al*. 2007, Arora 2006). In addition, the rice-wheat cropping system dominates in the northern part of India, so CropSyst modeling is suitable to evaluate the performance of several crop systems under different pedoclimate and crop water management conditions. Sole water regime and nitrogen level effects of different field management interventions for productivity of transplanted rice and wheat on grain and biomass are well documented in the literature. However, not much is known about their integrated effect. Thus, the present study was conducted to evaluate the performance of transplanted rice-wheat crop system under varied water and nitrogen levels and to quantify its interactive effect by simulating productivity using CropSyst model.

MATERIALS AND METHODS

Field experiments were carried out at the experimental research farm of Indian Agricultural Research Institute, New Delhi, India (28°64' N, 77°17' E and 228.61 m above msl) during *kharif* and *rabi* seasons of 2006-07 and 2007-08. The soil was deep alluvial clay loam (*Typic haplustept*) developed under hyper-thermic regime (USDA classification). Soil physical (texture, bulk density (Mg/m^3), FC 0.02 MPa, PWP 1.5 MPa and hydraulic conductivity (m/sec)) and chemical (EC (dS/m), pH, OC (%), NH_4^+ and NO_3^-) properties of the field 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 sampling was done at one month interval and also before sowing and after harvesting of the crop while the physico-chemical properties were analyzed using standard procedures (Table 1).

A total of 12 treatments were replicated thrice in 36 plots of size 7.5 × 6.75 m in split plot design with three levels of water regimes as main plot and four levels of nitrogen as subplot treatments for both crops (Table 2). The amount of irrigation was applied through flexi hoses and measured by water/flow meter for both the crops. Rice seedlings of 30 days old were transplanted with 20 cm row and 10 cm plant spacing on two times puddled soil in standing water followed by planking. Recommended agronomic practices were carried out for both crops. Biomass at one month interval after transplanting was measured from 1 m row length in each treatment and was oven dried at 60°C to constant weight. At maturity, the crop was harvested from the whole plot excluding the non-experimental border strips along the experimental plots and the yield was determined at 14% moisture content for both the crop. Plant samples were estimated for leaf area, above ground biomass (dry weight at 60°C) and total plant nitrogen content.

Table 1 Physico-chemical properties of the experimental site (transplanted rice-wheat)

Soil properties	Depth			
	0-15 cm	15-30 cm	30-60 cm	60-90 cm
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)	0.377	0.248	0.159	0.166
Permanent wilting point (m^3/m)	0.135	0.123	0.060	0.060
Hydraulic conductivity (m/day)	0.047	0.028	0.153	0.048
Field capacity (m^3/m)	0.232	0.225	0.170	0.176
Bulk density (g/cc)	1.44	1.46	1.60	1.67
Organic carbon (%)	0.55	0.50	0.31	0.25
NH_4^+-N (kg N/ha)	3.94	5.22	4.89	3.52
NO_3^--N (kg N/ha)	3.94	4.26	3.36	1.02

The increase of leaf area during the vegetative period, expressed as leaf area per unit soil area (leaf area index (LAI)) was calculated as a function of biomass accumulation:

$$\text{LAI} = \frac{SLAB}{1 + P^b}$$

where LAI is in m^2/m^2, B is accumulated aboveground biomass (kg/m^2), SLA is the specific leaf area (m^2/kg) and p is a partition coefficient (m^2/kg) controlling the fraction of biomass to leaves (a value of zero apportion all biomass to leaves) (Stockle and Nelson 2003).

Yield simulation depends on total biomass accumulated at physiological maturity (B_{PM}) and the harvest index (HI= harvestable yield/aboveground biomass):

$$Y = B_{PM}\ HI$$

where Y is yield (kg/m^2) and B_{PM} is also in kg/m^2.

Temperature is an important climatic factor which can have a profound effect on the yield of crops mainly through phenological development processes. Differential response to temperature change by various crops has been shown under different production environment (Kalra et al. 2008). Daily weather on maximum and minimum temperature, maximum and minimum relative humidity, wind speed and rainfall during crop growth period were obtained from meteorological observatory at Division of Agricultural Physics and WTC, IARI, New Delhi.

The model is designed to study the effect of cropping system management on crop productivity, water and N balance and the environment (Stockle *et al*. 1994 and Stockle *et al*. 1999). Simulations were made by selecting a location and soil, and building crop rotations with management schedule. The location parameters included longitude, latitude, weather files and Evapo-Transpiration models.

Table 2 Experimental details for transplanted rice and wheat

Treatment	Transplanted rice (2006)	Transplanted rice (2007)	Wheat (2006-07)	Wheat (2007-08)
Main plot				
Maximum irrigation	Continuous flooding (W_1)	Continuous Flooding (W_{11})	05 (W_1)	05 (W_{11})
Medium irrigation	One day drainage (W_2)	One day drainage (W_{21})	03 (W_2)	03 (W_{21})
Minimum irrigation	Three day drainage (W_3)	Three day drainage (W_{31})	02 (W_3)	02 (W_{31})
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), 100% P & K (75 kg P_2O_5 and 45 kg K_2 O)

The soil parameters included specification of soil layers thickness, texture, bulk density, cation exchange capacity, pH, and volumetric water content at water potentials of 0.02 M Pa (Field capacity) and 1.5 M Pa (Wilting point). The management options in the model included cultivar selection, crop rotation, irrigation regimes, nitrogen fertilization, tillage operations and residue management. The crop file comprised of common set of parameters related to classification, growth, morphology, residue, nitrogen, harvest index and phenology of the crop to represent different crops and crop cultivars. Model outputs taken were biomass and grain yield at harvesting of the crop.

The CropSyst model was calibrated using observed data on phenology, morphology, growth and harvest from the experiment conducted during 2006-07 for transplanted rice and wheat in rice –wheat cropping system. The other parameters of the crop file were taken as default with slight adjustments which were made within the range chosen from the CropSyst manual or reported by other researchers, so that the periodic crop growth like phenological stages, periodic biomass production and final grain yield were matched with the observed values. The crop parameters used in the model for calibration are given in Table 3.

Sensitivity analysis (SA) is a fundamental tool in the building, use and understanding of mathematical models of all forms (Tarantola and Saltelli 2003). SA provides information about the behaviour of the simulated system ranging from the identification of relevant model factors (parameters or inputs) to model reduction or simplification, to better understanding of the model structure for given components of a system, and to model quality assurance, hence to model building/development in general. SA measures the change in the model output in a localized region of the input factors' space (as generated from the distributional range of values). Sensitivity analysis was done for various crop input parameters, viz. maximum harvest index, N uptake adjustment, maximum N concentration at emergence, maximum N concentration at maturity, minimum N concentration at maturity, ET crop coefficient etc. 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.

The following indicators were used to test the prediction capability of the model.

Modeling efficiency: The modeling efficiency (ME), the measure of the deviation between model prediction and measurements relative to the observed data (Wu *et al.* 1999) was calculated using Nash and Sutcliffe (1970) relationship. The unit value showed a perfect fit between measured and simulated data and negative values are not acceptable (Confeloneiri 2006).

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

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

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

The root mean square error (RMSE): The RMSE is frequently used measure of the difference between values predicted by a model and observed values. 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.

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

The values equal to zero for the model shows a perfect fit between the observed and the simulated data.

Mean absolute error: The MAE measures the average magnitude of the errors in a calibrated and observed data, without considering their direction. It measures accuracy for continuous variables

$$MAE = \frac{\sum_{i}^{n} \mathrm{I}O_i - Si\mathrm{I}}{n}$$

Mean biased error (MBE) is a measure of overall bias error or systematic error between the observed and the

Table 3 Crop parameters for CropSyst simulation of growth and yield of transplanted rice and wheat in rice-wheat cropping system

Parameter	TP rice (2006)	TP rice (2007)	Wheat (2006-07)	Wheat (2007-08)
Observed parameters				
Degree-days emergence (°C-day)	121	118	62	71
Degree-days peak LAI (°C-day)	1925	1600	800	950
Degree-days flowering (°C-day)	1977	1543	748	947
Degree-days maximum grain filling (°C-day)	2235	1730	969	1084
Degree-days maturity (°C-day)	2510	2235	1337	1441
Maximum expected leaf area index (LAI)	6.5	6.5	6.0	6.0
Maximum Harvest Index	0.35	0.35	0.50	0.50
N uptake adjustment (0-2)	0.20	0.20	0.20	0.20
Maximum nitrogen concentration at emergence (kg/kg)	0.06	0.06	0.07	0.07
Maximum nitrogen concentration at maturity (kg/kg)	0.01	0.01	0.001	0.001
Minimum nitrogen concentration at maturity (kg/kg)	0.0015	0.0015	0.0001	0.0001
Extracted from CropSyst manual				
Maximum water uptake rate (mm per day)	13	13	15	15
Light to above ground biomass conversion (g/MJ)	4	4	3.5	3.5
Parameter set by calibration				
Specific leaf area (m^2/kg)	22	22	25	25
Stem/leaf partition coefficient	1	1	1	1
Leaf duration (°C-day)	900	900	1050	1050
ET crop coefficient	1.6	1.6	0.80	0.80
Critical canopy water potential (J/kg)	-1300	-1300	-1600	-1600
Wilting canopy water potential (J/kg)	-2200	-2200	-2500	-2500
Biomass/transpiration coefficient (kPa)	7	7	7.5	7.5
Site specific data from literature				
Cutoff temperature (°C)	40	40	30	30
Optimum mean daily temperature (°C)	30	30	18	18
Maximum root depth (m)	1.5	1.5	2.0	2.0
Base temperature	10	10	6	6

simulated parameters

$$MBE = \frac{\sum_{i}^{n}(O_i - Si)}{n}$$

Coefficient of residual mass (CRM) - This indicator shows the difference in observed and simulated data.

$$CRM = \frac{\sum_{i=1}^{n} Oi - \sum_{i=1}^{n} Si}{\sum_{i=1}^{n} Oi}$$

Its zero value denotes the perfect fit. Negative and positive values shows over and under prediction

RESULTS AND DISCUSSION

Field experiments

Transplanted rice and wheat yields were influenced by water regimes and different levels of nitrogen during the year 2006-07 and 2007-08 and results are presented in Table 4. The average rice yields were 3.50 and 3.61 Mg/ha in the year 2006 and 2007 respectively while those of wheat were 3.26 and 3.32 Mg/ha respectively for the year 2006-07 and 2007-08. The results were statistically within close range for rice while a slight decrease in the yield of wheat was observed. The decrease in observed wheat grain yield may be due to the heavy rain showers received when wheat was flowering. It was observed that continuous flooding significantly increased the grain yield in rice and wheat in both years followed by irrigation after one day drainage and irrigation after three days drainage in case of transplanted rice. A similar trend was observed in case of wheat. Five irrigations at crop critical stages tend to increase the grain yield in both the years followed by three and two irrigations. Data on effect of irrigation levels on grain yield showed that irrigation after one day drainage for rice and 3 irrigations at critical crop stages for wheat can be adopted to produce the average yield of the crops at

Table 4 Mean performance of rice-wheat cropping system under water and N regimes

Treatment/ Water regimes	Transplanted rice (Mg/ha)												Wheat (Mg/ha)											
	2006				2007				Pooled 2006 and 2007				2006-07				2007-08				Pooled 2006-07 and 2007-08			
	W_1	W_2	W_3	Mean	W_1	W_2	W_3	Mean	W_1	W_2	W_3	Mean	W_1	W_2	W_3	Mean	W_1	W_2	W_3	Mean	W_1	W_2	W_3	Mean
T1	2.37	2.16	1.97	2.16	2.59	2.35	1.94	2.29	2.48	2.25	1.95	2.23	2.54	2.32	2.11	2.32	2.73	2.43	2.21	2.46	2.63	2.38	2.16	2.39
T2	3.45	3.44	2.94	3.28	3.75	3.21	3.02	3.33	3.60	3.33	2.98	3.30	3.55	3.42	3.01	3.33	3.66	3.35	3.23	3.41	3.61	3.38	3.12	3.37
T3	4.60	3.82	3.56	3.99	4.63	4.44	3.63	4.23	4.61	4.13	3.60	4.11	3.72	3.62	3.23	3.52	4.35	4.13	3.82	4.10	4.03	3.88	3.52	3.81
T4	5.05	4.57	4.07	4.56	5.05	4.54	4.13	4.57	5.05	4.55	4.10	4.57	4.13	3.79	3.62	3.85	4.52	4.33	4.01	4.29	4.32	4.06	3.82	4.07
Mean	3.87	3.49	3.14	3.50	4.01	3.64	3.18	3.61	3.94	3.56	3.16	3.55	3.49	3.29	2.99	3.26	3.81	3.56	3.32	3.56	3.65	3.42	3.15	3.41
CD (P = 0.05)																								
Year (Y)								NS											0.152					
Water regimes (W)								0.104											0.067					
Y × W								NS											NS					
N Levels (N)								0.120											0.077					
Y × N								NS											0.109					
W × N								0.208											NS					
Y × W × N								0.294											NS					

the time of non availability of good quality irrigation water.

Integrated effect of water and nitrogen levels result in rice and wheat grain yield of 3.55 and 3.41 Mg/ha respectively. Pooled comparison of the data showed that with increase in nitrogen concentration from 0 to 180 kg/ha, grain yield was increased by 104.9 and 70.29 %, respectively for rice and wheat in cropping system. Moosavi and Mohamadi (2014) reported that increasing the N rate from 0 to 90 kg/ha increased the rice yield by 84.5 % due to improved nitrogen use efficiency while De Datta (1986) reported that yield increase of upto 1.8 tonnes/ ha was due to increased uptake by roots at N rate of 70 kg/ha. In addition, N increases flower formation percentage by supplying the protein needed by pollens to move through stigma and reach to ovule by increasing effective pollination; leading to formation of stronger embryo sac which favours the increased grain yield (Rahemi 2004). A reduction of 9.6 and 19.7% was observed with treatment of water regimes from W_1 to W_2 and W_1 to W_3. The corresponding values for wheat were 6.3 and 13.7% respectively. It has been inferred from the pooled two year data that the substantial water saving can be done but the yield was reduced by 9.6 and 19.7% in rice and 6.3 and 13.7% in case of wheat which can be neglected at the time of rising global water stress.

SIMULATION STUDY

CropSyst calibration

The model was initialized each time prior to rice sowing in the cropping season of 2006-07 (Table 3). During the first step of calibration, simulated phenological stages (germination, flowering, physiological maturity) were matched with the observed by adjusting the degree days (Table 3). Soil file for the experimental site was prepared using observed data on soil physic-chemical properties (Table 2). Location file was prepared from weather parameters recorded at the meteorological observatory. The crop management file for rice crop was also prepared from the management operations performed on different dates in the experiment.

CropSyst validation

The calibrated model was validated on the independent data set observed in the year 2007-08. The result of simulation clearly showed that the value of simulated yields were in agreement to those in observed ones with high correlation coefficient R^2 (0.87-0.96) and modeling efficiency ME (0.79-0.95) for both grain and biomass yield in transplanted rice and wheat (Table 5). Scatter plot of simulated and observed periodic biomass and grain yield (Fig 1) for transplanted rice and wheat under different water regimes and nitrogen levels provides the evidence that CropSyst can be used for predicting the yields. The different model evaluating criteria used to quantify the goodness of fit between observed and simulated biomass and grain yield as RMSE, MBE, MAE and CRM were also within the acceptable range (Table 5).

Table 5 Statistical summary comparing observed data with simulated values for rice-wheat cropping system using CropSyst

		N	Observed mean	Predicted mean	MAE (Mg/ha)	R^2	RMSE (Mg/ha)	ME (%)	*CRM* (Mg/ha)	*MBE* (Mg/ha)
TP Rice	Biomass (Mg/ha)	24	10.13	10.22	0.459	0.95	0.491	0.95	-0.0088	-0.089
	Grain yield (Mg/ha)	24	3.55	3.58	0.249	0.91	0.309	0.89	-0.0076	-0.027
Wheat	Biomass (Mg/ha)	24	6.91	6.91	0.175	0.87	0.223	0.95	-0.0002	-0.001
	Grain yield (Mg/ha)	24	3.44	3.46	0.512	0.93	0.609	0.79	-0.0059	-0.020

In transplanted rice, the model performed well at all levels of N for grain and biomass yield. Similarly, the model performed well at higher levels of N i.e. 180 kg/ha in case of wheat grain and biomass yield. Contrary to these results, it had been found by different researchers that in direct seeded rice at higher levels of nitrogen, the CropSyst model deviated for grain yield and biomass due to more N losses in the form of NH_3 volatilization and depletion of exchangeable NH_4^+-N due to increase N uptake (Singh *et al*. 2013, De Datta *et al*. 1989, Santhi *et al*. 1998, Erguiza 1990). Transplanted rice suffered from transplanting shocks during first 20 days after fertilizer application, delaying NH4^{+}-N depletion, the factor that has been incorporated in the CropSyst model (Diehmann 1990).

The CropSyst model also responded well to different levels of irrigation with significant R^2 values. In pooled statistical analysis, R^2 values were lower for grain and biomass yield (Table 5). Also other statistical tools such as CRM, RMSE, MAE and MBE were higher for biomass than grain yield. Thus the model is potentially more accurate in predicting grain yield than biomass. In rice, the RMSE for biomass was 5% of the observed mean and 9% in grain yield. The corresponding values for wheat are 3 and 18% respectively. This indicates that the model was accurate

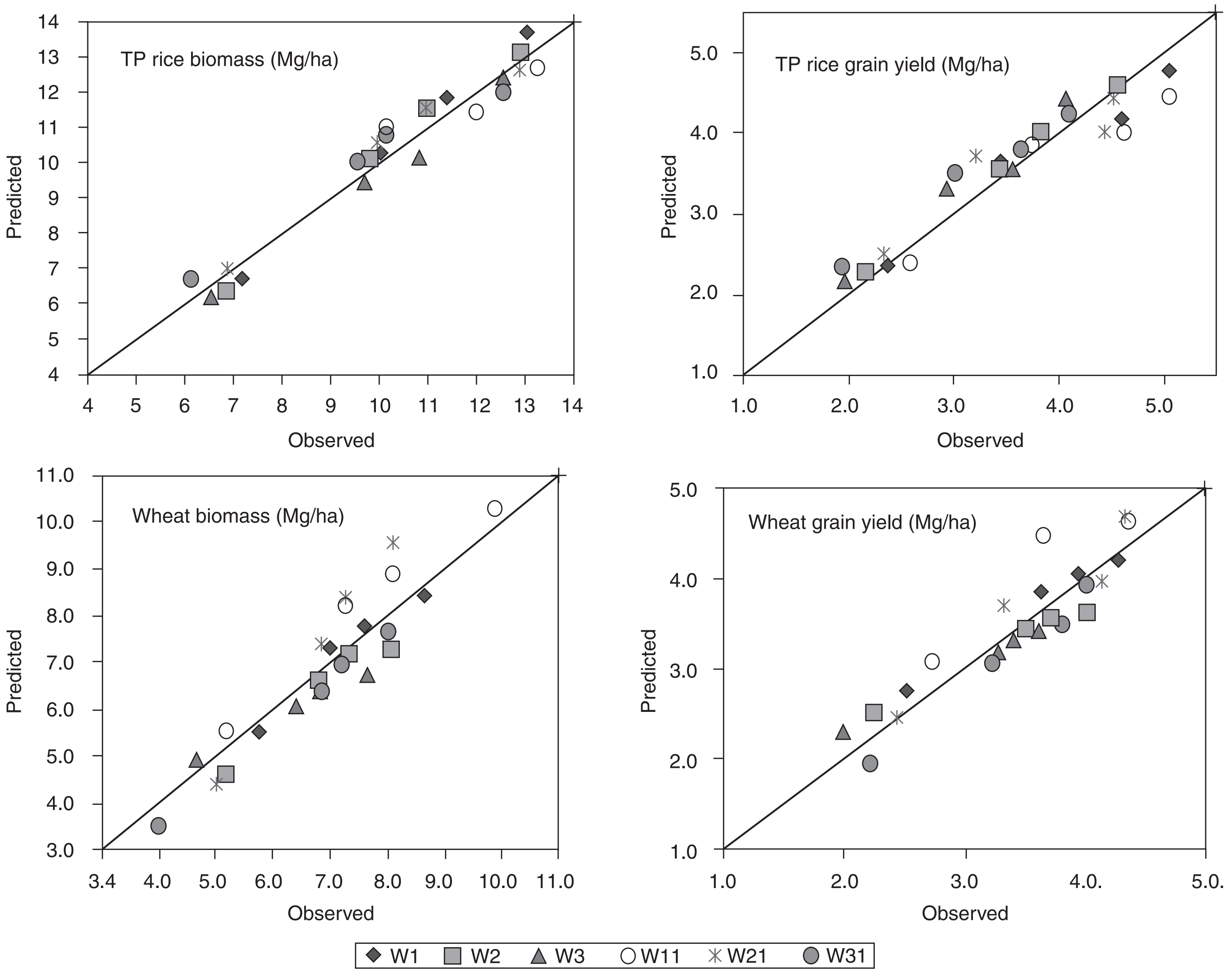


Fig 1 Observed and predicted biomass (Mg/ha) and grain yield (Mg/ha) of rice and wheat under maximum (W_1, W_{11}), medium (W_2, W_{21}) and limited (W_3, W_{31}) irrigation for all nitrogen treatments in rice-wheat cropping system.

at predicting yield and biomass of transplanted rice and wheat in rice–wheat cropping system. It had been reported by other researchers that RMSE for spring wheat were 7, 13 and 13% of the observed mean for evapo-transpiration, grain yield and above ground biomass respectively (Pannkuk *et al*. 1998, Wang *et al*. 2006). Also the higher R^2 values for biomass and yield indicated that the model was fit for predicting the two parameters (Jalota *et al*. 2006).

During calibration and validation of the CropSyst model, some deviations in the data occurred but these may be due to the variability of the field and inaccuracy in measured data in experimentation and these must be kept in mind while comparing the field data with the data generated from the model (Pannkuk *et al*. 1997, Feng *et al*. 2007).

Sensitivity analysis

To test the CropSyst model sensitivity to several crop input parameters, sensitivity analysis was done by varying the values of the crop input parameters by ± 5, ± 10, ± 15 and ± 20% to find the per cent change in predicted outputs 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 (Nash and Sutcliffe 1970). For CropSyst, the simulation of aboveground biomass was mainly based on the efficiency of the conversion of transpired water into biomass and radiation use efficiency (RUE). Above ground biomass was also a product of all crop parameters, acting in conjunction with each other. The results are presented in Table 6 and Fig 2. No change was observed in biomass yield upon sensitivity analysis for crop input parameters of maximum harvest index, cut off temperature (Table 6).

The model highly sensitive to light to above ground biomass conversion (g MJ^{-1}), optimum mean daily temperature and phenological degree days which accounts for more than ± 10% variation in biomass yield (Table 6). Among these, light to above ground biomass conversion almost had the same effect on per cent change in biomass on both the positive and negative side. But the effect of optimum mean daily temperature was high on negative side than on the positive side and the effect of phenological degree days is much high on negative side and very less on positive side. Thus, optimum mean daily temperature and phenological degree days need more accuracy in determination.

Biomass variation of ± 5-10% was due to base temperature, specific leaf area, leaf duration and maximum N concentration at emergence (Table 6). The rest of the parameters were found to affect the biomass production by only ± 5% as evident from the Table 6.

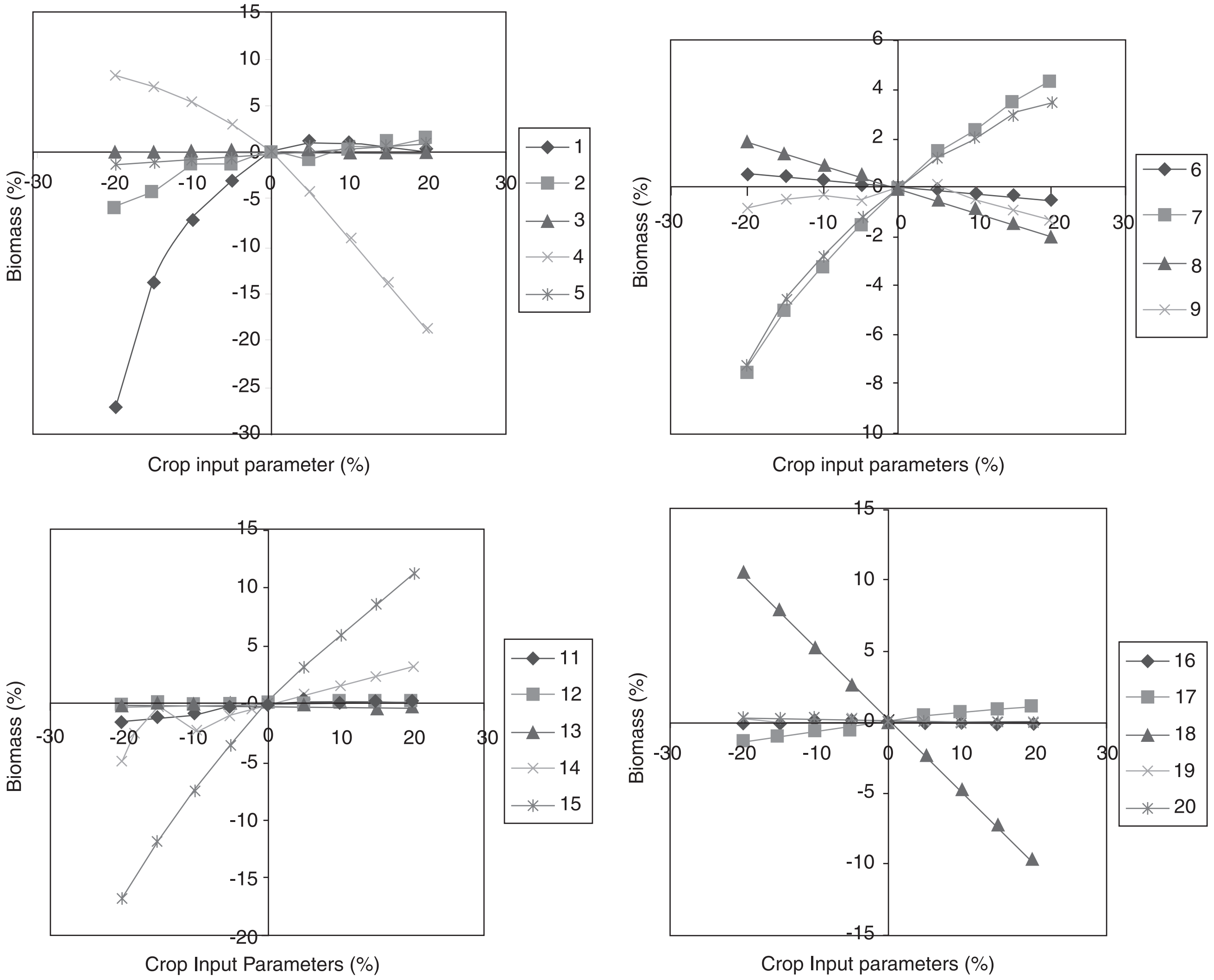
In the model, above ground crop growth is represented in terms of above ground biomass accumulation, which depends on intercepted radiation, transpiration (water dependent) and plant nitrogen uptake (nitrogen dependent) which is capable of limiting plant growth. The optimum temperature for growth is the temperature above which growth will not be affected and also affects the biomass accumulation indirectly. Evapo-transpiration 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. 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. Also the yield decreases with increase in critical canopy water potential, stem-/-leaf partition coefficient and vice versa.

Table 6 Percentage change in biomass of the various crop input parameters by varying the parameter in CropSyst model

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

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 (Stockle and Nelson 2003), which rely on light-to-biomass conversion coefficient (*LtBC*, as kg/MJ), and the water-to- biomass conversion ratio (*BTR*, as kg/m^3 kPa). The dry matter partitioning is also simple and based on one empirical equation and the 'leaf area/plant biomass' ratio at the early growth stages (*LAR*, as m^2 leaves/kg plant) and the stem-leaf partition coefficient (*SLP*, as m^2/kg), that accounts for the sharp decline of LAR as biomass accumulates over time (Stockle and Nelson 2003).

The study presented findings on grain yield and biomass under different water regimes and N treatments for transplanted rice and wheat, and calibration, validation and sensitivity analysis of the CropSyst model for grain and



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 ($kg\ kg^{-1}$)

Fig 2 Schematic representation of the sensitivity analysis of various input parameters used in CropSyst model.

biomass yield. Average grain yield of rice and wheat was 3.55 and 3.41 Mg/ha, respectively. With increase in nitrogen concentration from 0 to 180 kg/ha, seed yield was increased by 104.9% and 70.29%, respectively for transplanted rice and wheat in the rice–wheat cropping system. Grain yield can be reduced up to 20 and 14% by decreasing the irrigation water in rice and wheat, respectively. The CropSyst model adequately simulated the biomass and grain yield at all levels of N (Up to 180 kg/ha) for transplanted rice and with strong positive correlation coefficient at all levels of N and water regimes. RMSE for biomass and grain yield in rice and wheat indicates that the model is more accurate in predicting grain and biomass yield. CropSyst model is sensitive to light to above ground biomass conversion (g/MJ), optimum mean daily temperature and phenological degree days and is not sensitive to maximum harvest index and cut off temperature for estimating biomass and yield of transplanted rice and wheat in rice – wheat cropping system. The findings are limited to rice and wheat growth at one site only so more trails should be conducted for general conclusions to be made.

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