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Evaluation of the APSIM Model in Rice-Lentil Cropping System in a Complex Coastal Saline Environment

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Coastal ecosystems face numerous constraints, including erratic rainfall distribution, seawater intrusion, water stagnation with saline water, seasonal escalation of soil salinity, fluctuations in groundwater table depth, and variable moisture availability in the crop rhizosphere. While rice in the *Kharif* season navigates these challenges with the aid of monsoon rains, for reliable crop yield and productivity, crops in the *Rabi* season encounter multiple limitations due to low and variable rainfall. The shallow groundwater and surface drying drive the upward movement of salts into the root zone which coupled with soil drying and waterlogging events cause severe constraints for winter cropping. The spatial and temporal variability of these processes creates a complex interplay of climatic and soil factors with crop performance. A model-based crop simulation approach can help to resolve such complex interactions. In this study, we undertook the parameterization, calibration, and validation of the APSIM-Oryza and APSIM-Lentil models to simulate diverse experimental treatments within a rice-pulse cropping system across two seasons in the southern part of West Bengal, India. The model predicted observed biomass and grain yield well for both rice and lentil crops in the cropping system, with high coefficients of determination and acceptable RMSE values. Similarly simulated values during calibration and validation for grain yield and biomass of both rice (grain: RMSE = 331 [SD_{obs} = 401] and 193 [SD_{obs} = 203]; biomass: RMSE = 431 [SD_{obs} = 743] and 465 [SD_{obs} = 683]), and lentil (grain: RMSE = 79.1 [SD_{obs} = 64] and 192 [SD_{obs} = 237]; biomass: RMSE = 50.4 [SD_{obs}= 47] and 222 [SD_{obs} = 124]) and water use efficiency across various irrigation and salinity levels for rice and lentil exhibited satisfactory accuracy and precision. This validated model has the potential for predicting climate change scenarios and assessing agronomic impacts and adaptations in coastal saline regions. Considering the pivotal role of winter legume crops in soil fertility, income, and food security, the APSIM-Lentil model can be further used for developing resilient and sustainable practices in the face of complex environmental challenges.

(***Key words:*** *APSIM, Cropping systems, Lentil, Rice, Salinity, Shallow water table*)

Agriculture in the extensive coastal zone of West Bengal is vulnerable to extreme conditions, such as erratic rainfall patterns, seawater intrusions, floods, and recurrent cyclonic events that make agricultural activities risky. Cropping system intensification of this region is often constrained by several physical factors including waterlogging, poor soil structure, terminal heat stress, and off-season salinity distribution in the winter season (Paul *et al.,* 2020b). The farmers largely followed the monsoon-based mono-cropping pattern which is predominant in this region (Sarangi *et al.,* 2020). Aside from the elevated land around the farmhouse, the farmlands in this area are typically categorized as medium-upland, medium-lowland, and lowlands. Among these three types of land, the last two are frequently subjected to flooding and rainwater accumulation due to inadequate drainage during the rainy season (Banerjee *et al.,* 2018b; Sarkar *et al.,* 2019).

The agricultural calendar of this region is constrained by the long-duration traditional rice cultivation in the *Kharif* season, which delays the harvesting time and

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**Corresponding author:* E-mail: sukamalsarkarc@yahoo.com affects the timely sowing of subsequent crops (Paul *et al.,* 2020a). The late-cultivated *Kharif* rice cultivars are generally harvested in December or January. After rice harvest, the fields remain too wet for field preparation, which further delays establishment of the second crops. Therefore, *Rabi* season crops are exposed to deficient soil water, salinity, and terminal heat stress. The accumulation of salt on the soil surface intensified as the dry season advanced, driven by the upward capillary rise of saline groundwater (Brahmachari *et al.,* 2017).

Among the potential pulse crops, lentil (*Lens culinaris M.*) is popular in West Bengal accounting for around 10.5% of the total country's production (DoA, 2022). Its fast-growing ability, high yield potential, and short duration allow lentil to act as a catch crop and suitably fit in the crop calendar. However, in coastal saline zone (CSZ), the establishment of lentils is often delayed due to aberrant weather conditions, and excessive moisture in soil which lowers the yield (Ali *et al.,* 2012). Furthermore, after delayed planting, lentil in the CSZ is often hindered by terminal heat and excessive moisture stress in the reproductive stage (Ali *et al.,* 2012). In modern cropping systems simulation models are well suited for predicting crop performance under multiple crop stresses (Holzworth *et al.,* 2014; Jeuffroy *et al.,* 2014; Keating and Thorburn, 2018). The Agricultural Production Systems Simulator (APSIM), a framework-based model that simulates cropping systems under different potential scenarios, has been applied throughout the world, and is now calibrated for simulation of growth of 40 crops in a wide range of climatic conditions (Holzworth *et al.,* 2014). It is now validated for modeling rice-based cropping systems and effectively calibrated in multilocational climatic conditions across the Southern part of Asia (Gaydon *et al.,* 2017; Khaliq *et al.,* 2019; Mohanty *et al.,* 2020; Sarkar *et al.,* 2020b). However, the APSIM-Lentil model has not been tested in coastal ecosystems. Previous studies used a basic legume model with a combined data set to create a robust but general model for lentils (Robertson *et al.,* 2002). In this paper, we have used the APSIM-Lentil model to detail the construction and testing of the APSIM-Lentil model in the complexes of coastal saline agroecosystems.

MATERIALS AND METHODS

We have evaluated the performance of the APSIM model in predicting the soil salinity distribution and moisture changes based on the groundwater table data. Unlike the previous research, either the soil salinity inputs were used in the model directly or the values of irrigation water salinity were simulated as a factor. The field experiment was conducted from 2016-2018 on a farmer's field in Rangabelia village, Gosaba Block, South 24 Parganas, West Bengal, India (located at 21.92° N latitude and 88.80° E longitude). The experimental field was situated approximately 3.5 m (±0.5 m) above mean sea level (MSL). Daily meteorological data including maximum and minimum temperature, sunshine hours, relative humidity, and rainfall distribution, were recorded by an Automatic Weather Station (EM50 Data Collection System, Decagon Inc., WA, USA) positioned around 50 meters from the experimental plot throughout the experimental period (2016-2019).

Regional Research Station-Coastal Saline Zone, Bidhan Chandra Krishi Vishwavidyalaya (BCKV), and ICAR-Central Soil Salinity Research Institute (ICAR-CSSRI), Regional Research Station, Canning Town, West Bengal were the weather stations from where the long-term agrometeorological datasets (1986-2018) were collected on daily basis for the experiment. The temperatures ranges recorded in the experimental years varied between 18.6°C and 37.6°C, with a minimum and maximum temperature of 8.6°C and 28.6°C, respectively. This pattern closely follows the long-term mean air temperature. Throughout November to January, there was a consistent decrease in temperature. The relative humidity ranged between 49.6% and 88.8% during the experimental years. Average precipitation was observed at 212 cm during the two consecutive years for rice and lentil cropping season. The average solar radiation recorded for the experimental years was 16 MJ m^{-2} day^{-1}.

Physicochemical properties of soils and water

The experiments were done in medium upland and medium lowland fields. Both land situations featured diverse physicochemical properties along with fluctuations in surface water accumulation during the wet season. Before conducting the experiment, initial soil samples were taken with the help of a core sampler

Table 1. *Summary of physical and chemical soil parameters used for simulation in Gosaba, West Bengal, India (starting of rainy season experiment 2017)*

Soil depth (cm)	Clay (%)	Silt (%)	Sand (%)	Organic C (%)	Lentil LL (mm mm^{-1})	DUL	SAT	BD (g cm^{-3})	$EC_{1:5}$ (dS m^{-1})	pH
Medium-upland condition										
0-15	45.2	28.0	26.8	0.50	0.330	0.390	0.423	1.53	0.22	5.45
15-30	46.8	28.4	24.8	0.41	0.320	0.395	0.422	1.48	0.27	5.65
30-50	47.6	29.5	22.9	0.29	0.320	0.400	0.410	1.45	0.27	5.75
50-80	49.1	29.1	21.8	0.23	0.325	0.410	0.450	1.43	0.29	5.70
80-120	53.2	26.0	20.8	0.21	0.310	0.430	0.468	1.41	0.31	5.70
Medium-lowland condition										
0-15	47.9	27.6	24.5	0.51	0.330	0.400	0.430	1.51	0.13	5.65
15-30	48.1	28.7	23.2	0.46	0.320	0.410	0.423	1.45	0.24	6.05
30-50	48.3	28.3	23.4	0.44	0.320	0.420	0.460	1.43	0.25	5.62
50-80	50.5	29.5	20.0	0.38	0.320	0.430	0.468	1.41	0.29	5.52
80-120	55.3	26.6	18.1	0.32	0.320	0.430	0.475	1.39	0.29	5.52

LL - Crop lower limit; DUL - Drainage upper limit; SAT - Saturated water content (%) ; BD - Bulk density

(80 cm) to measure the different soil characteristics like soil texture, bulk density (BD), and soil organic carbon (SOC) (Jackson,1969). The samples were taken from five soil depths (0-15, 15-30, 30-50, 50-80, and 80-120 cm). The various soil physicochemical properties of the experimental plots are shown in Table 1.The pedotransfer software was applied to investigate the water-retaining parameters like drainage upper limit (DUL), saturated water content (SAT), and crop lower limit (LL) (mm mm^{-1}) (Saxton *et al.,* 1986). A conductivity meter (Meter: Systronics, 363) was used to observe the soil salinity (EC) (soil:water ratio of 1:5) at normal room temperature (28°C).

The depth of the water table and the electrical conductivity (EC) of the groundwater of the experimental field were monitored every 7-day intervals by using piezometers installed at the experimental site to a depth of 5.48 m. The AQUA-CRE conductivity meter (version 2.0.1) was used to evaluate the groundwater quality. The periodic variability of electrical conductivity (EC) and soil water content (gravimetric method) were estimated at intervals of 15 days at the above-mentioned depth (Bhattacharyya *et al.,* 2018). To compare with APSIM simulated values, the transformation of the recorded soil electrical conductivity (EC) measurements (soil: water ratio of 1:5) to chloride deposition (kg ha^{-1}) is conducted, as outlined by Bandyopadhyay *et al.* (2003) and He *et al.* (2013). The various transformation equations used in this experiment were successfully tested in the distinct experimental fields of coastal saline zones of India and Bangladesh (Mainuddin *et al.,* 2020; Paul *et al.,* 2020a, 2020b; Sarkar, 2021).

Experimental treatments

For both years consecutively, field experiments were carried out in the *Rabi* and *Kharif* seasons (2016-17 and 2017-18). Six dates of rice sowing (cv. CR1017) were used in two different land conditions (medium-upland and medium-lowland) every week (15th June to 19th July) and were replicated four times. There were 48 plots, each measuring 20 m^2 (5 m x 4 m). Twenty-two-day-old rice seedlings were carefully moved into a row with a plant's spacing of 30 cm × 5-7 cm, two seedlings per hill. In the same field, after the rice crop was harvested, lentil seeds (cv. Maitree) were shown to improve the use of the remaining soil moisture. The Department of Agriculture, GoWB (DoA, 2012) recommended a fertilizer dose of 60:30:30: N: P_2O_5:K_2O kg ha^{-1}. This was applied to rice using urea for N, single super phosphate for P, and muriate of potash for K. The Department of Agriculture, GoWB (2012) recommended a basal fertilizer dose of 20:40:20: N: P_2O_5:K_2O kg ha^{-1} for lentil. Both crops were cultivated in fully rainfed environments. When it came to rice, the depth of the stagnant water changed during the crop's growth from 2 to 5 cm, and the rice field was drained of water seven days before harvest. After that, Sarkar (2021) and Sarkar *et al.* (2020d) have provided descriptions for overall management of crop standards, and other methods of agronomic management.

Experimental observations

Phenological data were observed for both rice and lentil during the experimental periods according to the APSIM phenological stages (Keating *et al.,* 2003). These data were used to calibrate and validate the APSIM model for simulating crop growth and yield under different climatic ecologies. To measure the above-ground biomass at various periods (30, 50, 70, and 90 days after sowing in rice; at 20 and 40 DAS days after sowing in lentil), ten plants (for both rice and lentil) were randomly chosen from each plot, uprooted, and cleaned. These plants were used to estimate the weight of biomass, and the yield-attributing characters while the economics of the crop were estimated for assessment of crop yield (Banerjee *et al.,* 2018a, b).

APSIM modeling

The APSIM model could connect different sub-modules and enable us to simulate different components of a cropping system. In simulating the rice and lentil cropping system of a coastal saline environment, we have used five soil sub-modules including SWIM3, SURFACEOM, SOILN, SOLUTE, and FERTILISER to simulate the physicochemical characteristics of soils. Moreover, the water balance model *i.e.,* APSIM-SWIM3 was applied to design a simulation model for optimizing the behavior of water and solute movement within the soil profile (Connolly *et al.,* 2002; Huth *et al.,* 2012). The daily changes in soil salinity and moisture content can be simulated by using SWIM3 (Soil Water Infiltration and Movement). We standardized the observed and simulated data of soil salinity distribution and moisture content by using the APSIM-SWIM3 parameters, regulated by soil water movement (layer-based K_s for saturated flow (mm day^{-1}), matric potential at DUL (cm), solute dispersity [dis (cm^2 h^{-1})/(cm h^{-1})] and the osmotic potential of crop based on Cl$^-$concentration [clslos (cm^3 µg^{-1})]. SURFACEOM and SOILN modules were used to simulate the dynamics of the crop residue decomposition left on the above-ground surface and the transformations of soil C and N within the soil profile, respectively (Gaydon *et al.,* 2017; Singh *et al.,* 2016). To estimate leaching and solute distribution in conjunction with the SWIM3 module, the SOLUTE module was utilized to monitor the solute equilibrium and the movement of the chloride ions underneath the soil profile layers (Holzworth *et al.,* 2006). Using a schedule covering several years, the FERTILISER module was utilized for specifying the method of application of a chemical fertilizer to an APSIM "system" (Mohanty *et al.,* 2020).

Crop modules

The APSIM-Lentil module was re-written and revised by Sarkar *et al.* (2020a) and Sarkar (2021) as a part of the CSI4CZ Project (https://aciar.gov.au/project/lwr-2014-073). The Lentil model was built on the basic architecture of the PLANT2 Module of APSIM (https://www.apsim.info/documentation/model-documentation/crop-module-documentation/plant/). This Lentil model does not simulate grain weathering, although some users have simulated the number of rainfall events during pod-fill (using the manager module) and used this as a surrogate of weathering damage. APSIM-Lentil can be used with a high degree of confidence for Gosaba, West Bengal, however, is currently being validated for a wider range of locations, varieties, and managements in South Asia (India, Bangladesh, Nepal, etc.).

External inputs

Various agrometeorological factors were used daily as inputs to the APSIM module *viz.,* minimum and maximum temperature, solar radiation, and distribution of rainfall, and the electrical conductivity of groundwater and depth of groundwater were used as external inputs to the APSIM as well. We examine these data from the APSIM climate file (met file) using APSIM-Manager for each simulation. Based on these inputs, APSIM simulated the dynamics of soil water and chloride in the crop root zone through the simulated water loss from the soil, capillary moisture rise, and crop uptake.

Calibration and validation process

First, the model was parameterized with regional soil types, climatic data, and the ascribed agronomical practices followed by calibration and validation using the two-year on-farm experimental database for rice and lentils. We calibrated the model with observed data from the first-year trial, mainly the genetic crop coefficients of both cultivars, while the soil characteristics are hard to measure, including the distribution of roots and depths, crop lower limit (LL), FBiom, Finert (Probert *et al.,* 1998) and saturated hydraulic conductivity (Ks), etc. Then data from the second year were validated using the previous year's calibrated parameters thereby the variables such as soil water content, soil chloride, crop growth stages, grain, and biomass yields. The different cultivar-specific parameters used in the APSIM calibration and validation process for both rice and lentil are depicted in Table 2.

Statistical analysis

We used linear regression on observed and simulated data to compare the grain and biomass yield for both crop rice and lentils along with soil water and chloride content for calibration and validation of the model. We also calculated for the linear regression between observed and simulated data the slope (α), intercept (β), and coefficient of determination (R^2). The model performance using the student's t-test of means assuming unequal variance P(t), and the absolute square root of the mean squared error (RMSE) was also evaluated as:

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{i=1,n}(S_i - O_i)^2}{n}} \qquad \dots 1$$

$$\mathrm{RMSE_n}(\%) = \left(\frac{\text{Absolute RMSE}}{\text{Mean of the observed}}\right) \times 100 \qquad \dots 2$$

where n is the number of data pairs and S_i and O_i are the simulated and observed data, respectively. When $\alpha = 1$, $\beta = 0$, $R^2 = 1$, $P(t) > 0.05$ (meaning observed and simulated data are identical at the 95% confidence level) and the absolute RMSE between simulated and observed values is comparable to (ideally less than) the standard deviation of the experimental measurements

Table 2. *Cultivar-specific parameters used in calibration and validation of APSIM-Lentil (cv. Moitree)*

APSIM Code	Description	Unit	Value	
			Lower limit	Upper limit
x_pp_hi_incr	Photoperiod	h	1	24
y_hi_incr	Rate of HI increase	1 $days^{-1}$	0.0148	0.0148
x_hi_max_pot_stress	Average stress at flowering	-	0.00	1.00
y_hi_max_pot	Maximum harvest index potential	-	0.20	0.40
tt_emergence	TT from emergence to end of juvenile phase	°Cd	410	410
est_days_emerg_to_init	Estimated days from emergence to floral initiation	d	70	70
x_pp_end_of_juvenile	Photoperiod	h	12.2	13.2
y_tt_end_of_juvenile	TT from end juvenile to floral initiation	°Cd	260	260
x_pp_floral_initiation	Photoperiod	h	1	24
y_tt_flowering	TT from flowering to start grain fill	°Cd	300	200
x_pp_start_grain	Photoperiod	h	1	24
y_tt_start_grain_fill	TT from flowering to start grain fill	°Cd	435	435
y_tt_end_grain_fill	TT from start to end grain fill	°Cd	60	60
tt_maturity	TT from maturity to harvest ripe	°Cd	1.0	1.0
x_stem_wt	Stem weight	g $plant^{-1}$	0	10
y_height	Plant canopy height	mm	0	5000

for that variable the model performs best at reproducing experimental data. Statistical comparisons between the total rice and lentil datasets were carried out to investigate how well the model performed in simulating various land conditions and sowing dates.

RESULTS AND DISCUSSION

Simulation of soil water and salinity dynamics

In the APSIM simulation model, both medium-lowland and medium-upland situations exhibited better agreement between observed and simulated chloride content (CC) (kg ha^{-1}) and volumetric soil water content (SWC) (cm^3 cm^{-3}) across the various soil depths (0-120 cm) (Table 3). The chloride content (CC) in the medium-lowland situation was remarkably lower than in the medium-upland situation. Seasonal salt distribution in the crop rhizosphere and water table depth play a crucial role in the growth and development of the crops in this region. The model successfully simulated the capillary rise, solute distribution pattern, and leaching of salts in the soil profile in these various crop-growing environments. Soil evaporation and infiltration of surface water continuously alter the shallow groundwater table of the coastal saline belt of this region (Mainuddin *et al.,* 2020; Sarkar *et al.,* 2023).

Simulation of phenology

Different sowing dates significantly influenced the duration of various phenological phases of both rice and lentil. Both APSIM-Oryza and APSIM - Lentil crop models precisely predicted stages of seedling emergence (lentil) panicle initiation (rice), flowering (all crops), and physiological maturity (all crops) in both medium-uplandand medium - lowland conditions (Figs. 1 & 2). In both experimental periods, the effect of the sowing time on the duration of growth stages was identical in both medium-upland and medium-lowland conditions. Delayed sowing decreased the duration of growth for both rice and lentil. Irrespective of sowing dates, under the medium upland and medium low land situations both rice and lentil crops took more time to reach their physiological maturity. According to Sarkar *et al.* (2022), early sown rice (15th June; 1st DOS) experienced a delay in physiological maturity by seven and six days for 2016 and seven and eight days for 2017, under both medium-upland and medium-lowland as compared to the late sown rice (19th July; 6th DOS). Like rice, early lentil took more time to reach physiological maturity compared to late lentil.

Like many other crop models, APSIM-Oryza and APSIM-Lentil exploit thermal time accumulation (cumulative degree days) for measuring the phenological stages (Bouman and Van Laar, 2006). Under saline ecosystem, the crop phenological features are greatly influenced by sowing date, since the high temperature, limited soil water, and salt stressors cause adverse growth conditions in later stages (Ghosh, 2018; Sarkar *et al.,* 2020a). Extended crop growth duration, coupled with extended grain filling periods, resulted in an increased number of effective grain and enhanced potential yield (Yang *et al.,* 2008). Moreover, the physiological maturity of crops was hastened by the salinity stress and this shortens the length of crop growth and hence the duration for filling of grains (Radanielson *et al.,* 2018). In this current experiment, the rice crop planted on 15th June (1st DOS) took one week more to complete its physiological maturity than that sown on 19th July. Apart from this, pulse crops show more sensitivity to stresses occurring due to unfavorable moisture, temperature, and salinity conditions throughout the several stages of growth. The yield of these pulse crops is constrained by the higher salt concentration and extreme temperature (Hanumantha Rao *et al.,* 2016; Meena and Lal, 2018). The APSIM-Lentil crop models are well adjusted with these variations in the phenological phases which are influenced by the several sowing dates.

Simulation of biomass and grain yield under saline conditions

The agreement between the simulated and observed grain yield and dry matter over time for both rice and lentil in both experimental years (2016-17 and 2017-18), was generally robust across both land situations (Figs. 3 & 4). The early sown crops exhibit a higher yield and biomass production than that of late-sown crops. The values of simulated and observed grain and the biomass yield of both rice and lentil are quite similar in the case of both calibration and validation of the models. The performance of rice in the model in terms of the various parameters for evaluation showed satisfactory results in both seasons. High correlation coefficients (R^2) were observed for both calibration and validation datasets

Table 3. *Statistics on the observed and simulated data for model performance evaluation*

Model	Variables	n	X_{obs} (sd)	X_{sim}	P (t*)	Intercept (β)	Slope (α)	R^2	RMSE	RMSEn (%)
Calibration	Chloride (kg ha^{-1})	20	2371 (274)	2308	0.88	443	0.80	0.91**	449.8	18.95
	Rice grain yield (kg ha^{-1})	12	4888 (401)	5151	0.11	1870	0.67	0.76**	331	6.78
	Rice biomass (kg ha^{-1})	12	11087 (743)	11161	0.90	1343	1.13	0.93**	431	3.87
	Lentil grain yield (kg ha^{-1})	12	665 (64)	740	0.12	5.57	1.12	0.96**	79.1	11.9
	Lentil biomass (kg ha^{-1})	12	2473 (237)	2291	0.15	182	1.24	0.93**	192	7.79
Validation	Chloride (kg ha^{-1})	20	2193 (356)	2315	0.79	315	0.91	0.89**	419.1	19.12
	Rice grain yield (kg ha^{-1})	12	4884 (203)	4824	0.73	651	0.85	0.80**	193	3.94
	Rice biomass (kg ha^{-1})	12	10871 (683)	10022	0.68	2688	1.22	0.98**	465	4.64
	Lentil grain yield (kg ha^{-1})	12	748 (47)	747	0.99	283	1.04	0.95**	50.4	6.7
	Lentil biomass (kg ha^{-1})	12	2372 (124)	2165	0.28	222	1.00	0.96**	222	9.39

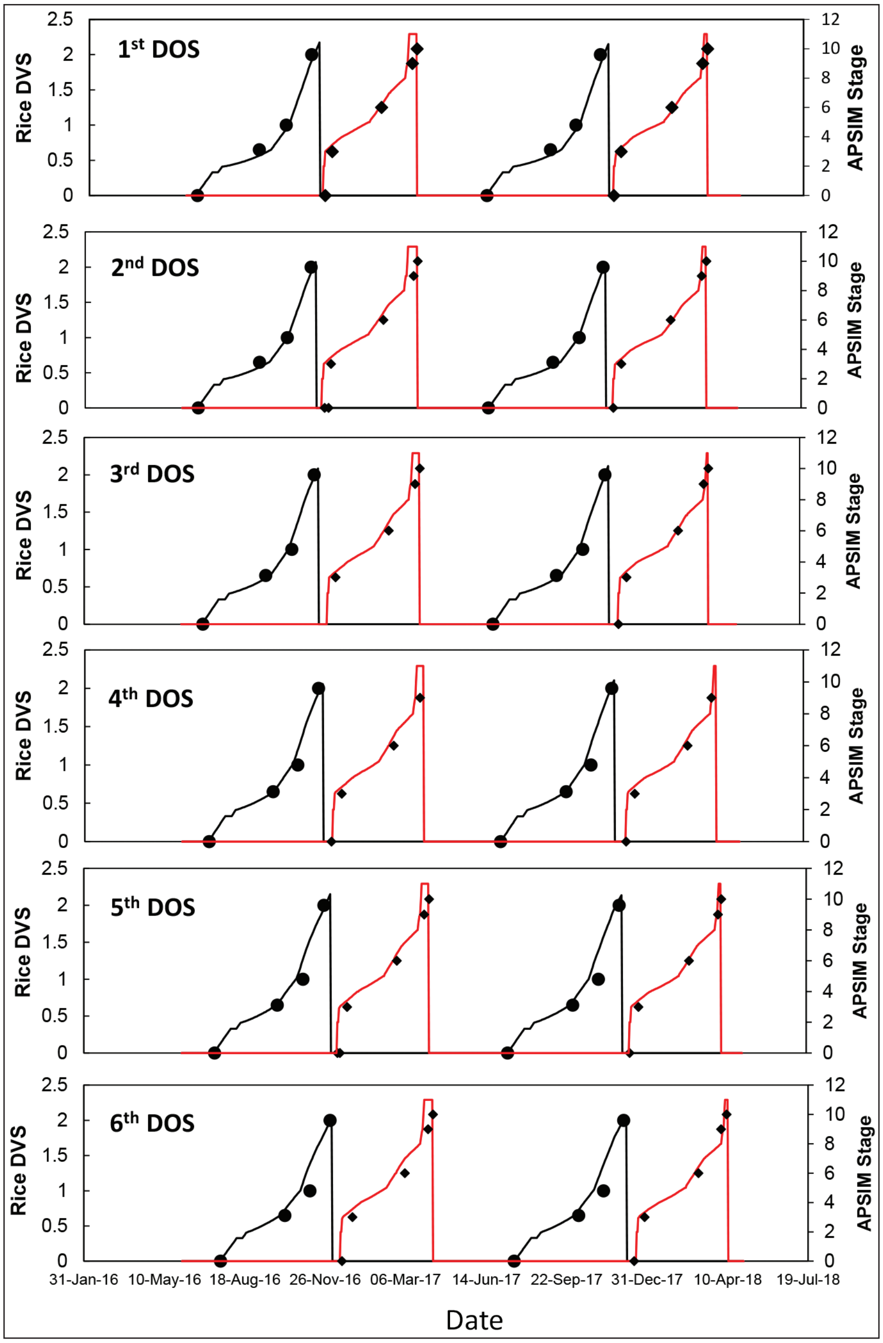

Fig. 1. *Comparison between observed (points) and APSIM-simulated (continuous line) crop phenology variables for rice (DVS, black) and lentil (Stage, red continuous) for the rice-lentil cropping system sown at different dates in the medium upland condition. [Abbreviation: For Rice: 1st DOS (Days after sowing): 15th June; 2nd DOS: 21st June; 3rd DOS: 28th June; 4th DOS: 5th July; 5th DOS: 12th July; 6th DOS: 19th July.; For Lentil: 1st DOS: 23rd November; 2nd DOS: 27th November; 3rd DOS: 2nd December; 4th DOS: 7th December; 5th DOS: 12th December; 6th DOS: 17th December]*

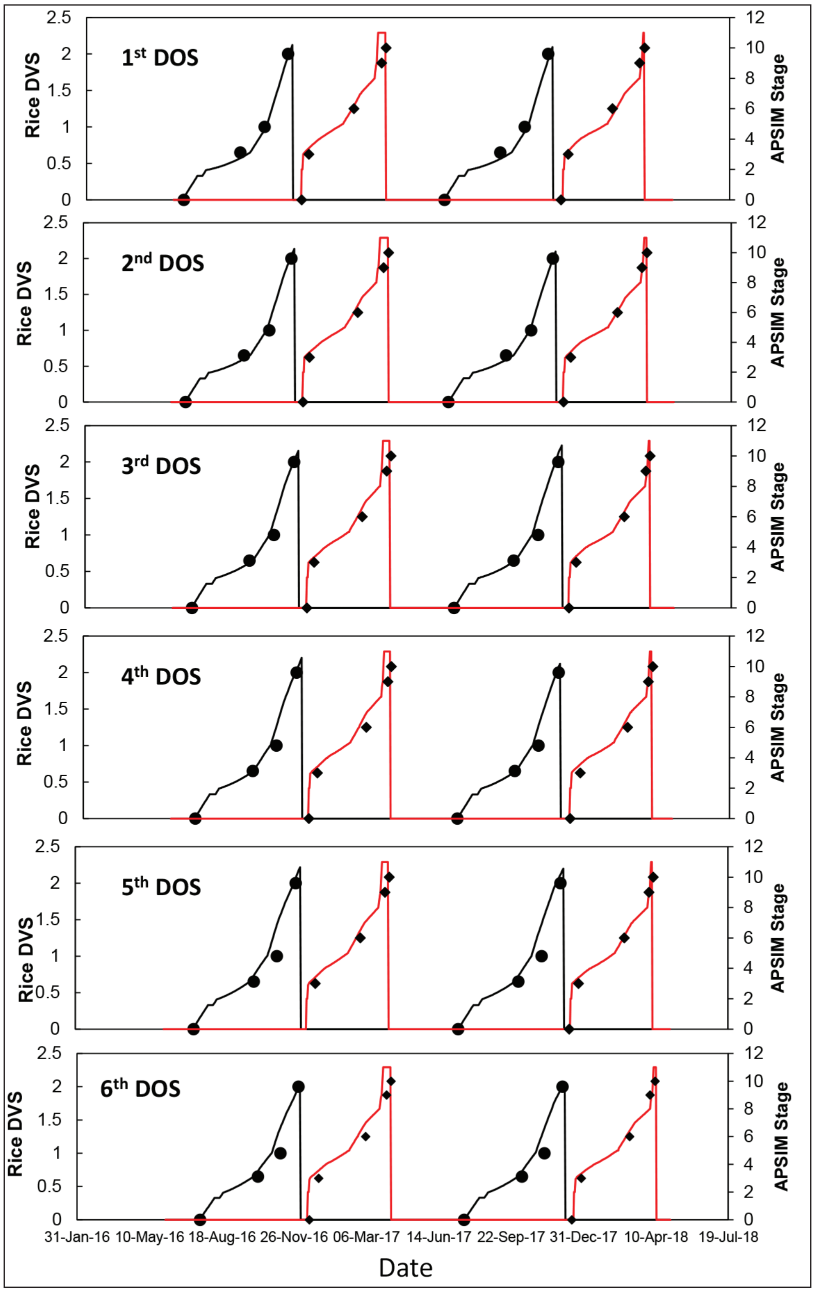

Fig. 2. *Comparison between observed (points) and APSIM-simulated (continuous line) crop phenology variables for rice (DVS, black) and lentil (Stage, red continuous) for the rice-lentil cropping system sown at different dates in the medium lowland condition. [Abbreviation: For Rice: 1st DOS (Days after sowing): 15th June; 2nd DOS: 21st June; 3rd DOS: 28th June; 4th DOS: 5th July; 5th DOS: 12th July; 6th DOS: 19th July.; For Lentil: 1st DOS: 23rd November; 2nd DOS: 27th November; 3rd DOS: 2nd December; 4th DOS: 7th December; 5th DOS: 12th December; 6th DOS: 17th December]*

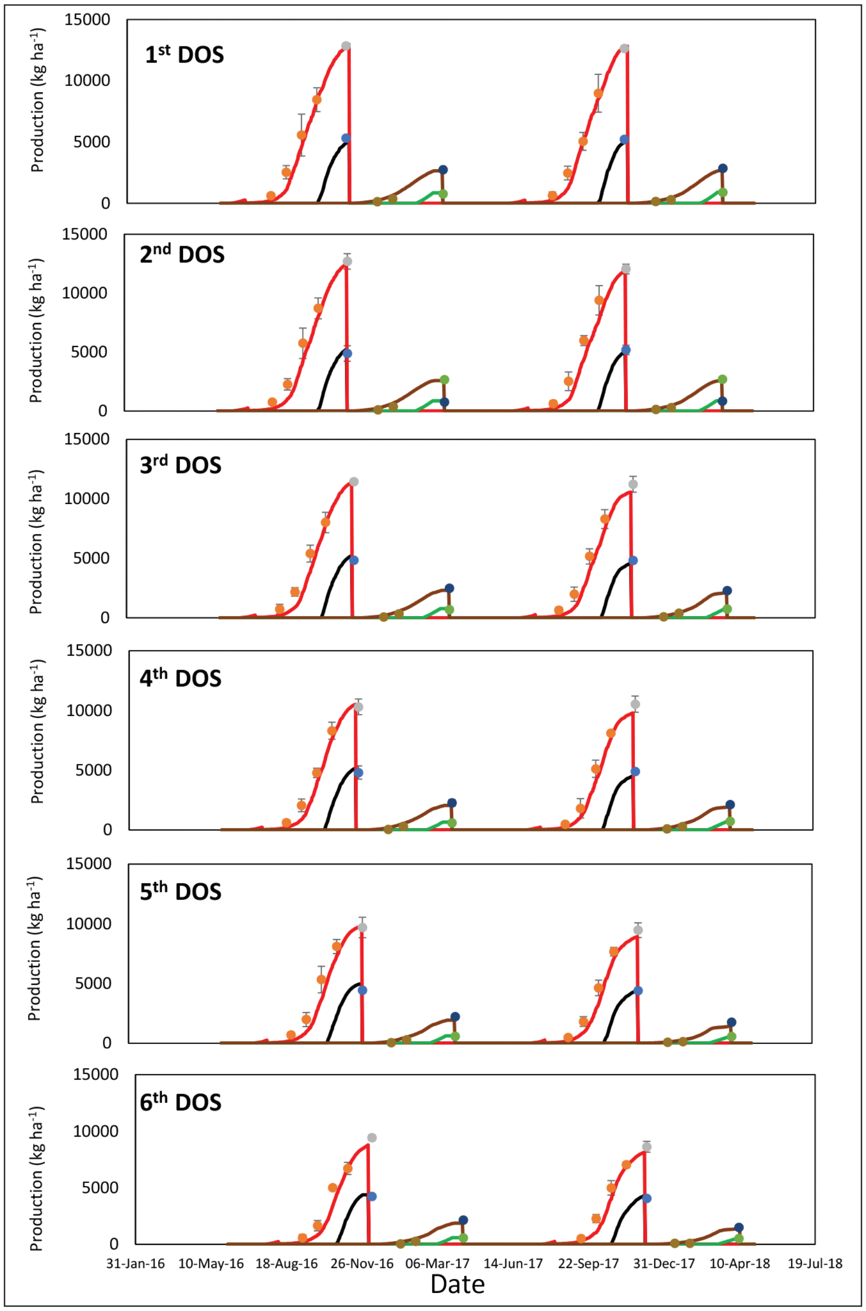

Fig. 3. *Simulated (red lines for rice and brown lines for lentil) and observed (symbols) above ground biomass (kg ha^{-1}) and simulated (black dotted lines for rice and green lines for lentil) and observed (symbols) grain yield (kg ha^{-1}) of the crops in rice-lentil cropping system sown in different dates under medium upland condition. [Error bars represent one standard deviation (across replicates) either side of the mean][Abbreviation: For Rice: 1st DOS (Days after sowing): 15th June; 2nd DOS: 21st June; 3rd DOS: 28th June; 4th DOS: 5th July; 5th DOS: 12th July; 6th DOS: 19th July.; For Lentil: 1st DOS: 23rd November; 2nd DOS: 27th November; 3rd DOS: 2nd December; 4th DOS: 7th December; 5th DOS: 12th December; 6th DOS: 17th December]*

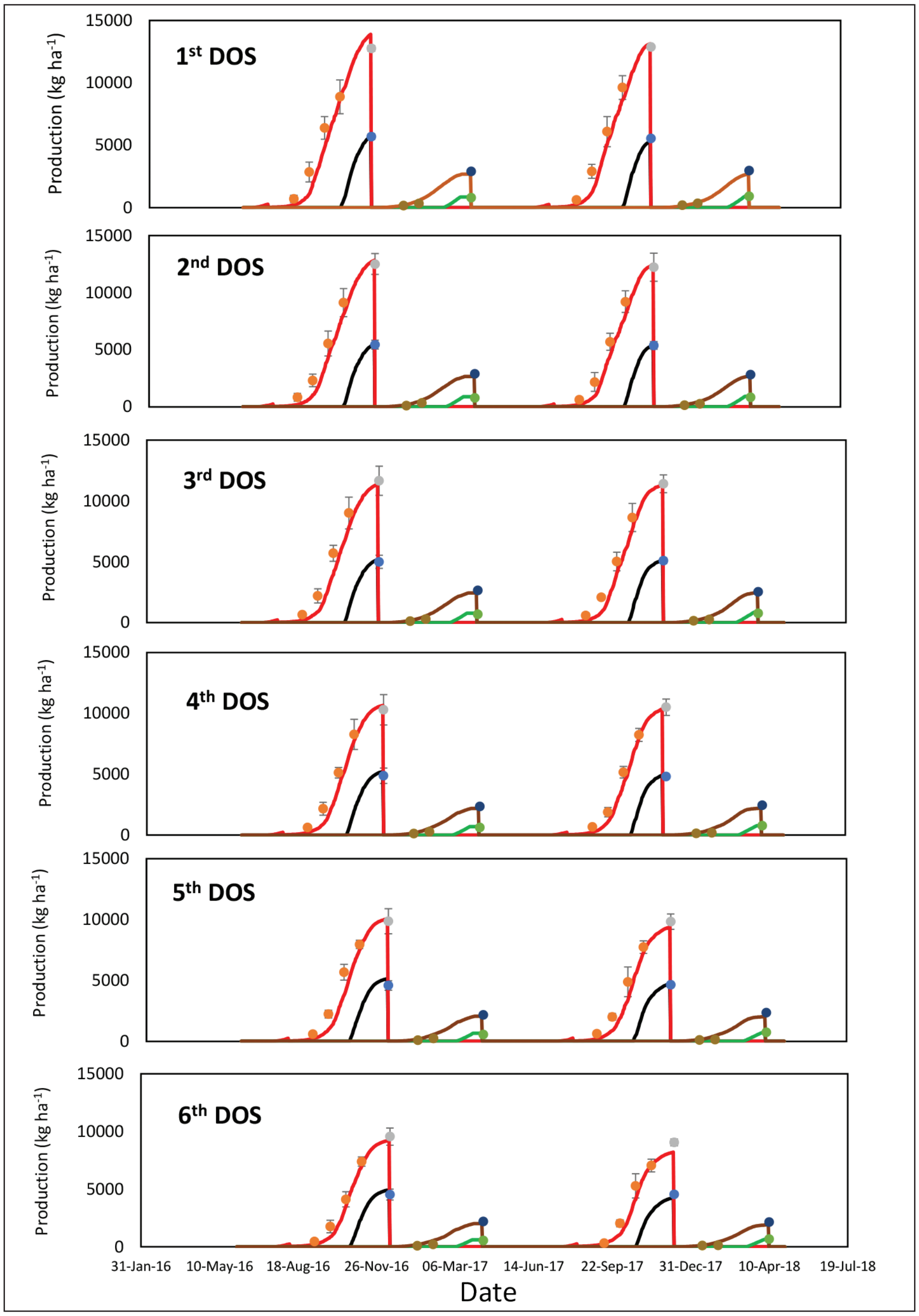

Fig. 4. *Simulated (red lines for rice and brown lines for lentil) and observed (symbols) above ground biomass (kg ha^{-1}) and simulated (black dotted lines for rice and green lines for lentil) and observed (symbols) grain yield (kg ha^{-1}) of the crops in rice-lentil cropping system sown in different dates under medium lowland condition. [Error bars represent one standard deviation (across replicates) either side of the mean][Abbreviation: For Rice: 1st DOS (Days after sowing): 15th June; 2nd DOS: 21st June; 3rd DOS: 28th June; 4th DOS: 5th July; 5th DOS: 12th July; 6th DOS: 19th July.; For Lentil: 1st DOS: 23rd November; 2nd DOS: 27th November; 3rd DOS: 2nd December; 4th DOS: 7th December; 5th DOS: 12th December; 6th DOS: 17th December]*

in terms of grain and biomass production (grain: R^2 = 0.76** and 0.80**; biomass: R^2 = 0.93** and 0.98** for calibration and validation datasets, respectively). Additionally, the root means square error (RMSE) for rice grain and biomass yield fell within the experimental uncertainty limits for both calibration and validation (grain: RMSE = 331 [SD_{obs} = 401] and 193 [SD_{obs} = 203]; biomass: RMSE = 431 [SD_{obs} = 743] and 465 [SD_{obs} = 683], respectively). The normalized RMSE values were 6.78% and 3.94% for grain yield and 3.87% and 4.64% for biomass, respectively. The APSIM-Lentil model showed better performance in the coastal saline belt of West Bengal. The R^2 of grain and biomass yield of lentil was high for both calibration and validation datasets (grain, R^2 = 0.96 and 0.95; biomass, R^2 = 0.93 and 0.96, respectively for calibration and validation datasets) (Fig. 6, Table 1) while the normalized RMSE was 11.9 and 6.7% for grain yield and 7.8 and 9.4% for biomass, respectively. The performance of lentil was better in year 2 than in year 1 (overall grain yield was 665 kg ha^{-1} in 2016-17 and 748 kg ha^{-1} in 2017-18), and variation among the years was also well recorded by the APSIM-Lentil model (Table 1). Treatment (sowing date and land situations) wise observed and simulated yield of grain and biomass of lentil for both calibration and validation datasets are represented in Fig. 5.

The APSIM model effectively recorded the impact of dates of sowing (treatments) on grain and biomass yield for both rice and lentil. The date of sowing is one of the most influential factors in the cultivation of rice (Singh *et al.,* 2018). The yield of rice often declines when the date of sowing of crops extends beyond the optimum sowing window (Pal *et al.,* 2017; Singh *et al.,* 2016). According to Sarkar *et al.* (2020c), sowing time must be adjusted in such a way that it guarantees optimum vegetative growth during the phase of ideal temperatures and extreme levels of solar radiation. In the present experiment, the crops sown earlier showed better performanceas compared to the crops that were late sown in terms of grain and biomass yield. In the

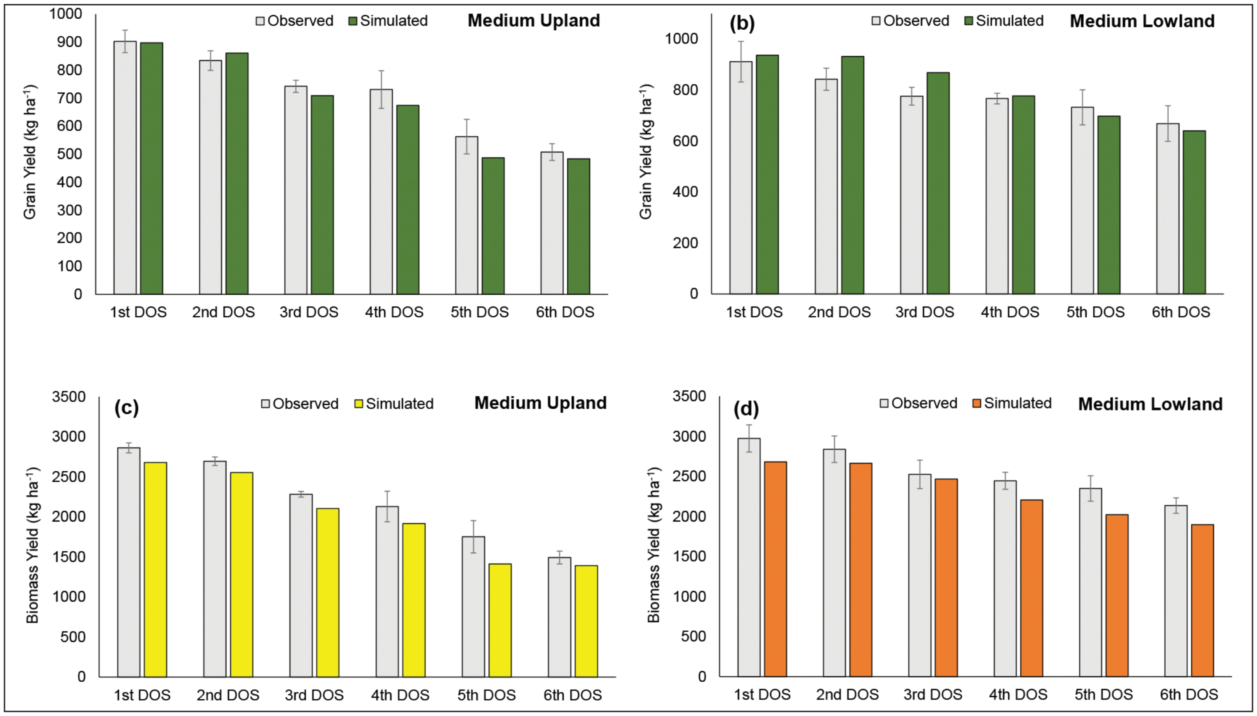

Fig.5. *Simulated and observed grain yield (kg ha^{-1}) and above ground biomass (kg ha^{-1}) of lentil for validation dataset grown under different sowing dates and land situations. [Error bars represent the standard deviation (across replicates) of the observed values; Fig. 5a and 5b for lentil grain yield; Fig. 5c and 5d for lentil biomass] [Abbreviation: For rice: 1st DOS (Days after sowing): 15th June; 2nd DOS: 21st June; 3rd DOS: 28th June; 4th DOS: 5th July; 5th DOS: 12th July; 6th DOS: 19th July.; For Lentil: 1st DOS: 23rd November; 2nd DOS: 27th November; 3rd DOS: 2nd December; 4th DOS: 7th December; 5th DOS: 12th December; 6th DOS: 17th December]*

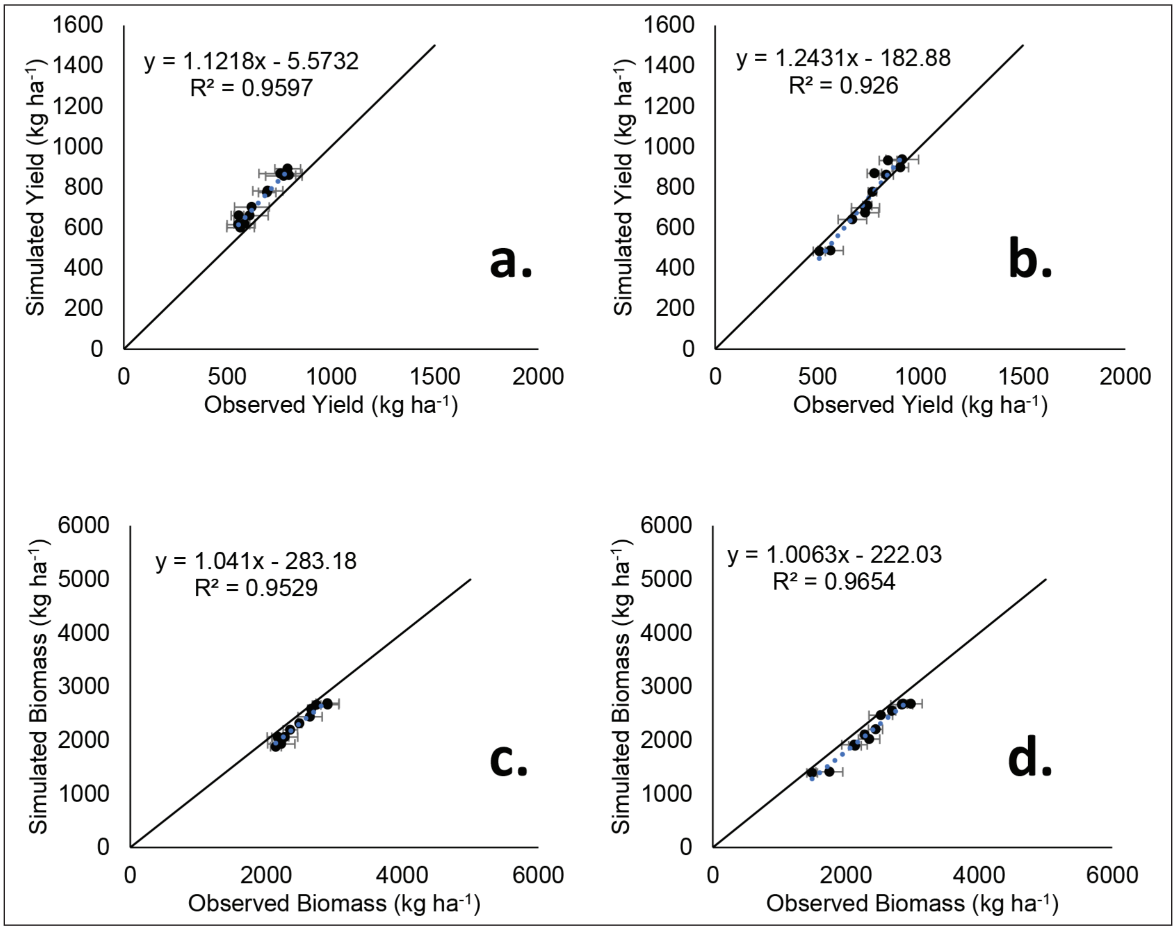

Fig. 6. *Simulated versus observed Lentil grain yield and biomass (kg ha^{-1}) (a) and (c) are the calibration data; (b) and (d) are the validation data. (Black continuous lines present the 1:1 line with an intercept at 0, while the blue dotted lines present the line-of-best-fit between simulated and observed values, horizontal error bars representing one standard deviation on either side of the mean across replicates of the observed values).*

case of early sown crops, the rate of remobilization of resources was found to be higher which may be linked with the higher dry matter production of crops(Pal *et al.,* 2017; Przulj and Momcilovic, 2001).

In the case of medium-lowland conditions, the grain and total dry matter yield for both crops is comparatively higher than for crops sown in medium-upland conditions and this result may be due to low salinity in the surface soil and higher soil moisture during most of the growing season. APSIM-Oryza and APSIM-Lentil captured these variations in land type for both seasons of the experiment.Time of sowing is one of the most crucial non-monetary farm practices which plays a vital role in managing the yield attributes by adjusting the residual soil moisture, heat, and salt stress as well as other biotic and abiotic factors. Terminal heat along with salinity stress are detrimental to the growth and development of pulse crops. According to Ranganathan and Rajalakshmi (2006), seed germination and young seedlings' growth are the most important and vital stages for any crop for its entire life cycle that is going to be subjected to a saline environment. The soil saline ecology in the coastal saline belt of West Bengal follows seasonal salinity dynamics. The upsurging of salt in the upper soil layer is generally observed from the end of March in CSZ (Mainuddin *et al.,* 2019a, b). Therefore, late sowing of pulse crops may have face detrimental impact on crop growth and yield, particularly in their reproductive stages. Consequently, early sowing of winter pulse irrespective of land type is recommended as a proactive strategy to minimise or avoid late-season salinity and terminal heat stress.

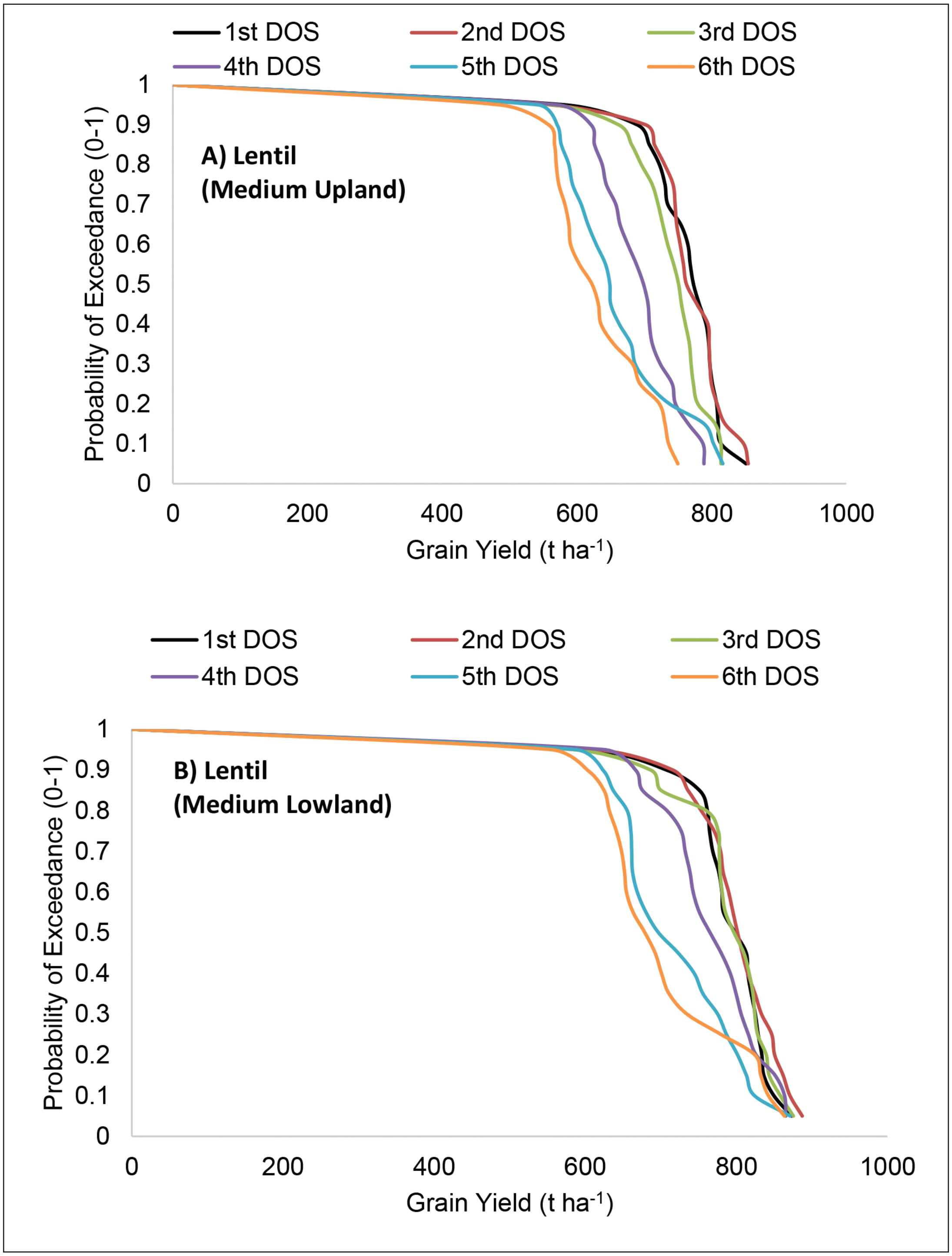

Fig. 7. *Effect of sowing date of rice on the probability of exceedance of lentil grain yield under rice-lentil system grown in a) medium upland and b) medium lowland condition [Historical Climate: 1986-2018]*

Hence, both the APSIM-SWIM3 and APSIM-Lentil models magnificently simulated the unique phenomenon of the complex coastal saline zone of West Bengal.

Scenario analysis

After calibration and validation of the APSIM-Oryza and APSIM-Lentil crop modules, the scenario analysis was performed using the long-term historical climatic data set (1989-2016). The results of the scenario analysis were presented in Fig. 7 as a function of probability of exceedance. In harmony with the previously calibrated and validated models, the performance of long-term simulations was satisfactory. From the probability curves, it was also clear that 15th June to 28th June (1st to 3rd DOS) for medium-upland condition and 15th June to 21st June (1st to 2nd DOS) for medium-lowland condition may be the optimum sowing window for rainfed rice to achieve maximum grain yield. Similarly, early sown succeeding lentil crops under different rice-based cropping systems performed satisfactorily under long-run scenario (Fig. 7). On the other hand, irrespective of land situations, early sowing of pulses between 23rd November and 2nd December resulted in significant higher probability of maximum yield with less chances of crop failure.

APSIM can be efficiently utilized to understand the negative impact of climate change. Liu *et al.* (2013) suggested that a well-calibrated and validated APSIM-Oryza model could elucidate variation in observed aboveground biomass and grain yield. This ability of APSIM might be an efficient way to understand the impact of the environment and selection of cultivars on crop productivity in the future.

CONCLUSION

A well-tested APSIM cropping system model was calibrated and validated under Coastal Saline agro - climatic zones. It performed satisfactorily in simulating complex research questions of numerous rice - lentil - based cropping systems. The APSIM - Oryza and associated APSIM - Lentil module performed quite satisfactorily in terms of simulating and predicting crop phenological changes, biomass, grain yield, and different soil processes. The modelling study also may be successfully used to understand and predict the dynamic behaviour of the soil water and salinity, as well as assist the farmers in selecting suitable crops, cultivars, cropping systems, and appropriate management practices. Thus, the APSIM model that captures interactions amongst soil-plant-atmosphere continuum, crop, and climate as well and farmer management, may provide the answers to different unsolved complex research questions and a handy decision support system for farmers, advisers and policymakers.

CONFLICTS OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

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