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Evaluation of rice and sweetcorn-based cropping system for rainfed upland ecosystem of Eastern India

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ABSTRACT : In the eastern India, rainfed area occupies nearly two-third of its total cultivable area. Rice is the predominant crop which is no more beneficial to farmers of the region due to its low yield. So there is a need to change in a cropping system and to find better crop substitution which can give more returns to the farmers than the existing system. With this view, the study was conducted at Indian Institute of Technology Kharagpur to evaluate rice and sweetcorn based cropping system for rainfed upland ecosystem of Eastern India. For this purpose two cropping systems, rice-peanut and sweetcorn-peanut were taken into consideration. Two crop growth simulation models *viz.*, CERES-rice and CERES-maize of DSSAT v4.0 (Decision Support System for Agrotechnology Transfer) were used to simulate the rice and maize yield of the region using historical weather data at Indian Institute of Technology Kharagpur for the years 1978 to 2007. The field experiment was carried out and the experimental data of yield components (yield and top weight) for the years 2009 to 2011 were used to calibrate and validate both the models. The comparative assessment of economic feasibility of the cropping systems (rice-peanut and sweetcorn-peanut) was also carried out to identify suitable cropping system for the region. The results of the models validated statistically which revealed that the models can predict the yield components with high accuracy. The net income from 1 hectare for rice-peanut and sweetcorn-peanut cropping pattern was Rs. 64415 and Rs. 90330, respectively. So it was concluded from the study that, for the rainfed upland ecosystem of Eastern India, sweetcorn-peanut cropping system was more beneficial than rice-peanut cropping system. Sweetcorn-peanut cropping system can be adopted for the sustainable development in the region.

KEY WORDS : CERES-maize, CERES-rice, Cropping system, DSSAT v4.0, Rainfed

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About 70 per cent of total cultivated area in eastern India is rainfed. Crop production in this farming system entirely depends on the behaviour of south-west monsoon. In spite of a high degree of rainfall ranging from 1194 to 2290 mm per year in the region, the farmer is not able to harvest a single crop successfully due to the erratic temporal and spatial variation in occurrence of monsoon. Unpredictable onset and withdrawal of monsoon accompanied by in-season long dry spells leading to drought situation have jeopardized the production system of rainfed crops.

Among various land situations of rainfed agriculture, the upland ecosystem is supposed to be the worst hit area of the vagaries of the monsoon. Rice, the staple food of the people in the region, is grown indiscriminately in all topographical situations irrespective of the return that the grower gets. Reports reveal that out of 7.1 M ha of upland rice area of the country, 6.2 M ha is from the eastern region only (CRURRS, 1995). In addition to the erratic and uneven distribution of monsoon rain, depletion of soil moisture soon after the cessation of rainfall and lack of assured source of irrigation in upland situation have minimized the scope of growing a second crop in post monsoon period as well as harvesting a good yield from the rice crop. Consequently the cropping intensity in the region is not increasing as compared to other regions of the country. The ecosystem is also equally affected by the human factors like growing high water requiring crops *i.e.* rice in such an unsuitable topography. Average yield of rice recorded in the region is 0.8-1.0 t ha^{-1} and the region contributes only 50 per cent of country's rice production (Ghildyal, 1989). Growing rice in the uplands during monsoon season has neither solved the total food grain requirement of our growing population nor boosted up the economy of the growers. Rather it has resulted in situations like distress sale of rice as well as shortage of other necessary food grains like pulses, oilseeds etc. So to say, the combination of natural and human factors has made the crop production system unsustainable in the region.

The major challenge in enhancing food grain production in eastern region comes from its rainfed uplands. Out of 44 million ha of total rice area in India, the upland rice occupies 7 million ha of which 75 per cent is from eastern India only (Kar *et al.*, 2004). The average yield of the crop from this topo-sequence is very low and unstable. The reasons are mostly attributed to monsoon aberrations, physical properties of the soil and socio-economic status. Most of the farmers possessing lands in upland topo-sequence are resource poor with very small land holdings. They are categorized as marginal and small farmers and constitute 58 per cent of farming community whereas; only 21 per cent of cultivable land is under their possession (Verma *et al.*, 2004). The average yield of cereals, oilseeds and pulses from the region are lagging behind the other regions of the country (NAAS, 1998). On the whole, a biased and faulty rice dominant cropping practice has not only resulted in lowering the cropping intensity in rainfed uplands but also contributed to bringing down the productivity. This paper deals with the study of calibration and validation of CERES- Rice and CERES-maize model of DSSAT for simulation of rice and maize yield and ccomparative assessment of economic feasibility of the cropping systems (Rice-Peanut and Sweetcorn-Peanut).

METHODOLOGY

Present study can be divided in three distinct parts. First part of study deals with calibration and validation of CERES-rice and CERES-maize using three years field experimental data. Simulation of rice and maize yields using historical weather data was carried out in second part of the study. In the final part of study, two cropping systems were taken into consideration (Rice-peanut and Sweetcorn-peanut) and comparative assessment of these cropping systems for their economic feasibility was carried out to identify most suitable cropping system for the region.

Study area :

Field experiments were conducted in the uplands of the experimental farm of Agricultural and Food Engineering Department, Indian Institute of Technology Kharagpur, India for three years during 2009 to 2011. The patch of land at relatively higher elevation than the surrounding fields has been referred as uplands in the present study. When the uplands in the farm are at altitude ranging from 41 to 48 m, the surrounding low lands are at 38 to 40 m above mean sea level.

Topography :

The natural topography of the study area is undulating and sloping downward. The existing land slope is within 2 per cent and it is prevalent in rainfed agricultural lands in the eastern region. In the process of making the crop fields leveled, the whole topo-sequence has been converted to bench terraces having certain elevation head difference between adjacent crop fields along the slope. This kind of field layout is very much prevalent in all upland rice areas of the region. Average elevation head difference between adjacent fields is 5 cm in the experimental site. Thus, the experimental site has the characteristics of a true upland situation that is prevalent in the eastern region of India. The site is located at $22^{0}19'$ N latitude and $87^{0}19'$ E longitude with an altitude of 48 m above the mean sea level.

Soil :

The soil in the experimental site was mostly acidic in nature and the average soils were grouped under sandy loam textural class. The pH of the soil varied from 4.8 to 5.6. Water holding capacity of the soil was very low. Erratic rainfall pattern, graded topography and faulty cropping practice have degraded the land resources in upland situations through erosion of top soil and loss of nutrients. The fertility status of the soil in the experimental site is also very low. The features of the soil and climate of the experimental site are very much prevalent in the rainfed uplands of the eastern region of India. Hence, the experimental site was presumed to be a true representative of the rainfed uplands of eastern India. Physical and chemical properties of the soil profile of the experimental site are presented in Table A.

Table A : Physical properties of the soil profile in the experimental site

Soil depth (cm)	Particle size distribution (%) Sand	Silt	Clay	Texture	Bulk density (g/cm)	SAT (mm/cm)	FC (mm/cm)	WP (mm/cm)	K_s (cm/h)
15	65	24	11	Sandy loam	1.60	3.6	2.0	0.9	0.512
30	68	22	10	Sandy loam	1.55	3.7	2.1	0.9	0.330
45	66	14	20	Sandy clay loam	1.48	4.0	2.2	1.0	0.280
60	59	18	23	Sandy clay loam	1.43	4.2	2.4	1.2	0.154
75	58	16	26	Sandy clay loam	1.41	4.3	2.5	1.4	0.128
90	45	27	28	Sandy clay loam	1.37	4.4	2.8	1.5	0.103
105	43	28	29	Clay loam	1.36	4.4	2.8	1.5	0.048
120	42	28	30	Clay loam	1.36	4.4	2.9	1.5	0.037

Field experiment :

The field experiment was conducted during wet season for rice and sweetcorn and during dry season for peanut to calibrate the crop simulation models CERES-rice and CERES-maize through using the experimental data. For this purpose, for rice and sweetcorn the varieties namely Annada and Sugar-75 were selected.

DSSAT :

DSSAT (Decision Support System for Agrotechnology Transfer) was used for simulating crop growth parameters (Hoogenboom *et al.,* 1994). The model was developed under the International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) project. DSSAT is an integrated software of different computer programmes, which can facilitate the application of crop simulation models in research and decision-making. It has much more flexible functionality for database manipulation and model application than any other existing crop growth simulation models. It enables the user to match the biological requirements of crops to the physical characteristics of land so that objectives specified by the user, may be satisfied. For the present study, the model CERES was used for the maize and rice crops.

Crop growth was simulated by employing a carbon balance approach in a source-sink system (Ritchie *et al.,* 1998). Daily crop rate was calculated as :

$$PCARB = \frac{RUE \times PAR}{PLTPOP}\left[1 - e^{(-KxLAI)}\right] * CO_2 \qquad \text{......(1)}$$

where, PCARB = Potential growth rate, g/plant; RUE =Radiation use efficiency g dry matter/ MJ PAR; PAR = Photo synthetically active radiation MJ m^2; PLTPOP = Plant population, plant/ m^2; K = Light extinction factor; LAI = Green leaf area index; and CO_2 = CO_2 modification factor.

Calibration and validation :

The CERES-rice and CERES-maize models were calibrated first to fit the model in the specific soil and environmental conditions. Genetic co-efficients for rice and maize and was calibrated using experimental data on biomass, LAI, grain yield etc.

Model evaluation strategy :

The model evaluation strategy was based on the comparison of the statistical characteristics of simulated data with that of the observed data. For model evaluation, the mean error (ME), the root mean square error (RMSE), model efficiency (EF), average deviation and co-efficient of determination were used. These statistics are defined as follows :

$$ME = (1/N)\sum_{i=1}^{N}(C_{si} - C_{oi}) \qquad \text{......(2)}$$

$$EF = 1 - \left[\frac{\sum_{i=1}^{N}(C_{si} - C_{oi})^2}{\sum_{i=1}^{N}(C_{oi} - C_o)^2}\right] \qquad \text{........(3)}$$

$$RMSE = \left[(1/N)\sum_{i=1}^{N}(C_{si} - C_{oi})^2\right]^{0.5} \qquad \text{.........(4)}$$

where, N = total number of data; C_{si} = simulated data; C_{oi}= observed data; and C_o = mean of observed data.

Application :

The model was used to simulate grain yield for the varieties Annanda and Sugar-75 of rice and maize, respectively at their optimum conditions for Kharagpur region using historical daily weather data (rainfall, maximum and minimum temperature, solar radiation) of past 30 year.

Economical analysis for evaluation of cropping systems :

Study of economic feasibility for rainfed rice and sweetcorn was carried out. Economic viability using sprinkler irrigation was evaluated for winter peanut. The seasonal cost of sprinkler irrigation included depreciation, prevailing bank interest rate, repair and maintenance of the system. The interest rate and repair and maintenance cost of the system were 12 and 2 per cent per annum of the fixed cost, respectively. The useful life of the sprinkler system was considered to be 9 years and that of pump was 15 years. The cost of production included expenses incurred in field preparation, cost of seeds, sowing, fertilizer, weeding, crop protection measures, irrigation water and harvesting. The yield of winter peanut and *Kharif* rice and sweetcorn cultivated in 1 ha area was estimated and economic analysis was carried out.

The fixed cost includes sprinkler system cost and cost of the pump. The depreciation was calculated by the following formula :

$$\text{Annual depreciation expences} = \frac{\text{Cost of fixed asset} - \text{Residual value}}{\text{Usefull if of aseet (years)}} \qquad \text{..(5)}$$

The seasonal benefit and benefit cost ratio was calculated by the formula :

Seasonal benefit = Cost of yield (Rs.) - Total seasonal cost (Rs.) **......(6)**

$$\text{Benefit cost ratio} = \frac{\text{Seasonal benefit}}{\text{Total seasonal cost}} \qquad \text{.......(7)}$$

According to procedure discussed above, the benefit cost ratios were calculated for rice-peanut and sweetcorn-peanut cropping system and comparative economic analysis was carried out to identify suitable cropping system for the region.

RESULTS AND DISCUSSION

The study was undertaken to evaluate rice and sweetcorn based cropping system for rainfed upland ecosystem of Kharagpur, India. In the study calibration and validation of two models (CERES-maize and CERES-rice) of DSSAT were carried out using the field experimental data of IIT Kharagpur. Simulation of rice and maize yields was also carried using the DSSAT model. To identify the suitable cropping system comparative assessment of economic feasibility of two cropping systems (Rice-Peanut and Sweetcorn-Peanut) was carried out. The results obtained from the study are discussed in subsequent sections.

Performance of CERES-maize model :

CERES-maize requires six parameters, known as "genetic co-efficients", to characterize different cultivars. These cultivar–specific genetic co-efficients affect development rates, organ growth and plant ontology. These co-efficients are constants in the model and are used to quantify differences in growth and development responses between different maize cultivars. These genetic co-efficients primarily depend upon the photoperiod, temperature and the genetic potential of the cultivar.

Calibration and validation of CERES-maize model :

The 2009 and 2010 experimental data were used for calibration and 2011 data for validation of model. The model was calibrated using the experimental data on grain yield, above ground dry matter and maximum leaf area index. The value of genetic co-efficients was estimated using the best-fit method (Table 1). Model calibration was performed for experiment and the best set of genetic co-efficients was obtained by trial and error method. The genetic co-efficients have a pre-assigned range and calibrated values needs to fall within that range. A fairly good agreement was found between simulated and measured grain yield of maize. It was also found that the simulated and measured above ground dry matter and leaf area index were matching reasonably well with each other.

Simulation of grain yield :

The measured and simulated grain yield for three years (2009-2011) revealed that the simulated grain yield matched well with the corresponding measured values for any experiment. Comparison of the simulated and measured grain yield at harvest for three years is presented in Table 2. A reasonably good agreement was found between simulated and measured values of grain yield during all experiments.

Simulation of leaf area index :

The temporal variation of simulated and measured maximum leaf area index for three years (2009-2011) revealed that the simulated and measured maximum leaf area index were in good agreement with the measured leaf area index.

Simulation of above ground dry matter :

The simulated above ground dry matter was found to be in good agreement with the measured above ground dry matter. In general, a good agreement was found between simulated and measured values of above ground dry matter during all experiments.

Time series analysis of tops weight of CERES- maize :

The simulated and observed tops weights at different plant growing stages were plotted in Fig. 1 to 3. The simulated

Table 1 : Calibrated genetic co-efficients of maize in CERES-Maize model

Parameters	Definition	Unit	Calibrated values
P_1	Thermal time from seedling emergence to the end of the juvenile phase (expressed in degree days above a base temperature of 8 °C) during which the plant is not responsive to changes in photoperiod	°C day	213
P_2	Extent to which development (expressed as days) is delayed for each hour increase in photoperiod above the longest photoperiod at which development proceeds at a maximum rate (which is considered to be 12.5 h)	Day	0.40
P_5	Thermal time from silking to physiological maturity (expressed in degree days above a base temperature of 8 °C)	°C day	634
G_2	Maximum possible number of kernels per plant	–	965
G_3	Kernel filling rate during the linear grain filling stage and under optimum conditions	mg/d	10
PHINT	Phylochron interval; the interval in thermal time (degree days) between successive leaf tip appearances	°C day	38

Table 2 : Comparison of measured and simulated yield, leaf area index and above ground dry matter of maize for year 2009-2011

Particulars	2009		2010		2011	
	Observed	Simulated	Observed	Simulated	Observed	Simulated
Yield at maturity (kg/ha)	5183	5117	4543	4508	1961	2414
Leaf area index	3.13	2.93	2.19	2.54	3.37	0.75
Tops weight (kg/ha)	10655	11342	8756	9825	5521	4541

tops weight was found to be good agreement with the observed values.

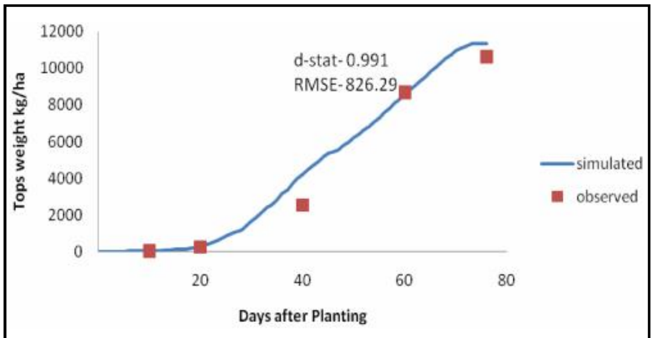

Fig. 1 : Comparison of measured and simulated tops weights of maize for different plant growing stages during the years 2009

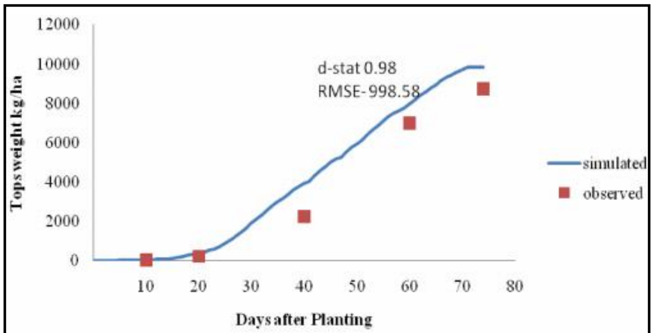

Fig. 2 : Comparison of measured and simulated tops weights of maize for different plant growing stages during the years 2010

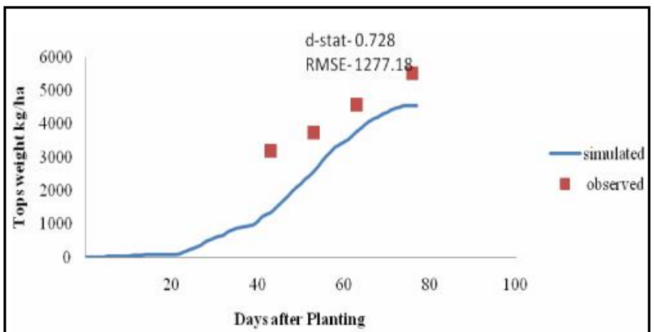

Fig. 3 : Comparison of measured and simulated tops weights of maize for different plant growing stages during the years 2011

The continuous line shows simulated tops weight while the dots show the measured tops weight at different plant growing stages. The simulation line shows that up to the 30 day after planting the tops weight increased slowly but as the plant grows rapidly, it showed rapid increase in tops weight. The simulated and observed values for year 2009 and 2010 shows good trend of matching as compared to 2011.

Evaluation of CERES-maize model :

The model was calibrated using 2009 and 2010 field experimental data and validated using 2011 field experimental data. Statistical analysis was performed to evaluate the performance of CERES-maize model in simulating the crop variables. The statistical analysis result given in Table 3 indicated that the model simulated grain yield, above ground dry matter and maximum leaf area index reasonably well. The values of statistical test parameters such as, mean error (ME), root mean square error (RMSE) and model efficiency (EF) revealed that the CERES-maize model simulated the crop variables with considerable accuracy and thereby can be recommended for further use under similar agro-climatic conditions.

Table 3 : Statistics for comparison amongst simulated and measured values of crop parameters

Crop parameters	RMSE	ME	EF
Grain yield (kg/ha)	265.07	117.33	0.96
Tops weight (kg/ha)	926.48	258.66	0.81
Leaf area index	0.96	0.82	0.88

Calibration and validation of CERES-rice model :

The 2009 and 2010 experimental data were used for calibration and 2011 data for validation. The model was calibrated using the experimental data on grain yield and above ground dry matter and maximum. The values of genetic co-efficients were estimated using the best-fit method (Table 4). Model calibration was performed for experiment and the best set of genetic co-efficients was obtained by trial and error method. The genetic co-efficients have a pre-assigned range and calibrated values needs to fall within that range. A fairly good agreement was found between simulated and measured grain yield of rice. It was also found that the simulated and measured above ground dry matter was matching reasonably well with each other.

Simulation of grain yield :

The measured and simulated grain yield for three years (2009-2011) revealed that the simulated grain yield matched well with the corresponding measured values for any experiment. Comparison of the simulated and measured grain yield at harvest for three years is presented in Table 5. Reasonably good agreement was found between simulated and measured values of grain yield during all experiments.

Simulation of above ground dry matter :

The simulated above ground dry matter was found to be in good agreement with the measured above ground dry matter.

In general, a good agreement was found between simulated and measured values of above ground dry matter during all experiments (Table 6).

Time series analysis of tops weight of CERES- rice :

The simulated and observed tops weights at different plant growing stages were plotted in Fig. 4 to 6. The simulated

Table 4 : Calibrated genetic co-efficients of rice in CERES-Rice model

Parameter	Definition	Unit	Calibrated values
P_1	Time period from seedling emergence during which the rice plant is not responsive to changes in photoperiod. The period is also referred to as the basic vegetative phase of the plant.	°C day	820
P_2O	Critical photoperiod or the longest day length (in hours) at which the development occurs at a maximum rate. At values higher than P20 developmental rate is slowed, hence there is delay due to longer day lengths.	day	10.5
P_2R	Extent to which phasic development leading to panicle initiation is delayed (expressed as GDD in ^{0}C) for each hour increase in photoperiod above P20.	°C day	140
P_5	Time period in GDD ^{0}C) from beginning of grain filling (3 to 4 days after flowering) to physiological maturity with a base temperature of 9 ^{0}C	°C day	470
G_1	Potential spike let number co-efficient as estimated from the number of spikelets per g of main culm dry weight (less lead blades and sheaths plus spikes) at anthesis. A typical value is 55.	–	54
G_2	Single grain weight (g) under ideal growing conditions, *i.e.* non-limiting light, water, nutrients, and absence of pests and diseases.	G	0.027
G_3	Tillering co-efficient (scaler value) relative to IR64 cultivar under ideal conditions. A higher tillering cultivar would have co-efficient greater than 1.0.	–	1
G_4	Temperature tolerance co-efficient. Usually 1.0 for varieties grown in normal environments. G4 for japonica type rice growing in a warmer environment would be 1.0 or greater. Likewise, the G4 value for indica type rice in very cool environments or season would be less than 1.0.	–	1

Table 5 : Comparison of measured and simulated yield and above ground dry matter of rice for year 2009-2011

Particular	2009		2010		2011	
	Observed	Simulated	Observed	Simulated	Observed	Simulated
Yield at maturity (kg/ha)	3800	3742	2000	1935	4171	3650
Tops weight (kg/ha)	7200	6316	4200	3361	8261	6436

Table 6 : Statistics for comparison amongst simulated and measured values of crop parameters

Crop parameters	RMSE	ME	EF
Grain yield (kg/ha)	304.97	214.66	0.89
Above ground dry matter (kg/ha)	1267.02	1182.66	0.82

Table 7 : Economics analysis of cultivating rice, sweetcorn and peanut in a 1 ha area

Sr. No.	Economic parameters	Crop		
		Rice	Sweetcorn	Peanut
1.	Fixed cost (Rs.)			35700
2.	Seasonal cost of the system (Rs.)			8970
3.	Seasonal cost of cultivation (Rs.)	18155	29675	25980
4.	Seasonal total cost (Rs.)	18155	29675	34950
5.	Average market price of crop (Rs.) /100 kg	1090	390	2850
6.	Beneficial yield to be produce (100 kg./ha)	38	207.32	26
7.	Income from produce (Rs.)	41420	80855	74100
8.	Net seasonal income (Rs.)	23265	51180	39150
9.	Benefit cost ratio	1.28	1.72	1.12

tops weight was found to be good agreement with the observed values.

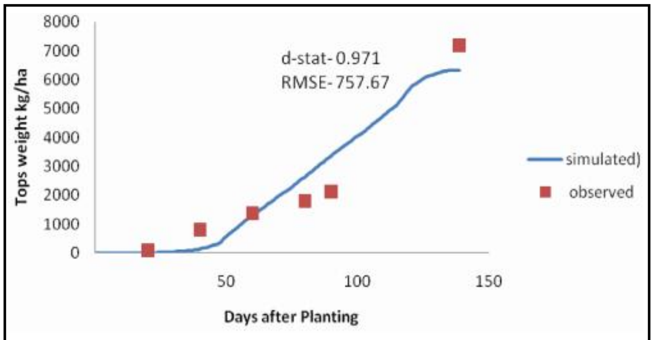

Fig. 4 : Comparison of measured and simulated tops weights of rice for different plant growing stages during the years 2009

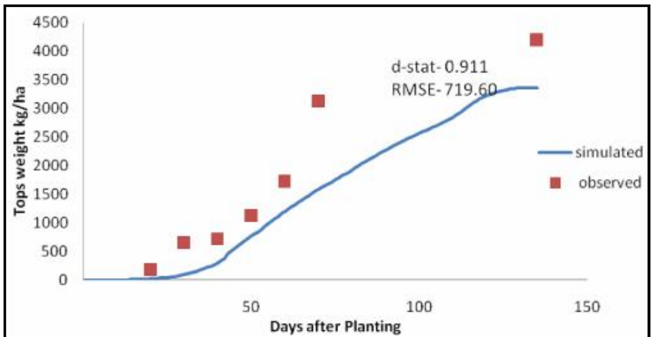

Fig. 5 : Comparison of measured and simulated tops weights of rice for different plant growing stages during the years 2010

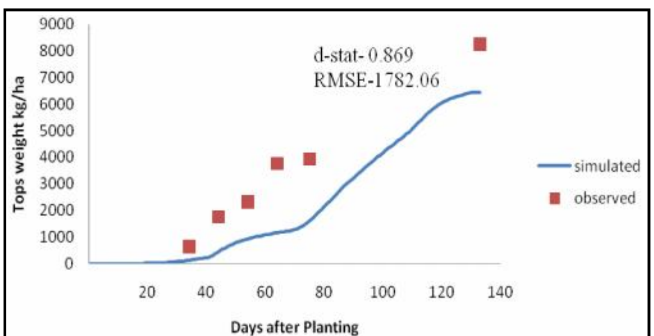

Fig. 6 : Comparison of measured and simulated tops weights of rice for different plant growing stages during the years 2011

The continuous lines shows simulated tops weight and the dots shows the measured tops weight at different plant growing stages. The simulation line shows that up to the 60 day after planting the tops weight increased slowly but as the plant grows rapidly, it showed rapid increase in tops weight.

Evaluation of CERES-rice model :

Statistical analysis was carried out to evaluate the performance of CERES-rice model in simulating the crop variables. The statistical analysis result given in Table 6 indicated that the model simulated grain yield and above ground dry matter and reasonably well. The values of statistical test parameters such as: mean error (ME), root mean square error (RMSE) and model efficiency (EF) revealed that the CERES-rice model simulated the crop variables with considerable accuracy and thereby can be recommended for further use under similar agro-climatic conditions.

Economic analysis :

The benefit cost ratios of rice, sweetcorn and peanut were found to be 1.28, 1.72 and 1.12, respectively. The benefit cost ratio of sweetcorn was higher than rice.

The total yearly cost of cultivation for rice-peanut cropping system was Rs. 53105 with net income of Rs. 64415. The total yearly cost of cultivation for sweetcorn-peanut cropping system was Rs. 64625 with net income of Rs. 90330. As the net income from sweetcorn-peanut cropping system was higher than that of rice-peanut cropping system. Therefore, it can be stated that out of two cropping systems, sweetcorn-peanut cropping system was more beneficial. Henceforth the study recommends the sweetcorn-peanut cropping system for the rainfed upland ecosystem of Eastern India. This cropping would be more beneficial for the farmers and would lead to increasing returns from agriculture.

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■ REFERENCES

CRURRS (1995). Booklet on upland rice research achievement and perspective. Central Rainfed Upland Rice Research Station, Hazaribag (JHARKHAND) INDIA.

Ghildyal, B.P. (1989). Rice production in eastern India-issues in rice research. *J. Agric.,* **1** : 79-91.

Hoogenboom, G., Jones, J.W., Wilkens, P.W., Batchelor, W.D., Bowen, W.T., Hunt, L.A., Pickering, N.B., Singh, U., Godwin, D.C., Baer, B., Boote, K.J., Ritchie, J.T. and White, J.W. (1994). Crop models. In: G.Y. Tsuji, G. Uehara and S. Balas (editors), DSSAT v3. Vol 2-2, University of Hawaii, Honolulu, Hawaii.

Kar, G., Singh, R. and Verma, H.N. (2004). Alternate cropping strategies for assured and efficient in upland rainfed rice areas of eastern India based on rainfall analysis. *Agric. Water Mgmt.,* **67**(1): 47-62.

NAAS (1998). Harnessing and management of water resources for enhancing agricultural production in the eastern region.Policy paper.3, National Academy of Agricultural Sciences, INDIA.

Ritchie, J.T., Singh, U., Godwin, D.C. and Bowen, W.T. (1998). Cereal growth, development and yield. In: G.Y.Tsuji (editor), *Understanding options for agricultural production*, Kulwer Academic Publishers, Great Britain, pp. 79-98.

Verma, H., Singhandhupe, R.B., Nanda, P., Kar, G. and Panda, D.K. (2004). Resource characterization for sustainable agriculture in AER 12. Resource analysis for sustaining water-food security. In: Selvarajan *et al.* (Eds), NCAP, New Delhi (India), Proceedings, **12**: 151-189.

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