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Validation of CERES-Rice v3.5 under the climate of Andhra Pradesh state, India

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सार - प्रयोगात्मक आँकड़ों से यथोचित रूप से प्रमाणित किए गए फ़सल की बढ़वार से संबंधित अनुकरति निदर्शों में कृषि के क्षेत्र में कुशल एवं नीतिपूर्ण निर्णय लेने की संभावना होती है। इस प्रकार के प्रमाणित किए गए निदर्शों से विशेष प्रकार के कार्यस्थल प्रयोगों तथा अन्य कार्यस्थलों एवं वर्षों के परीक्षणों के माध्यम से तैयार की गई सूचनाएँ भी प्राप्त कर सकते हैं। फ़सल अनुकरण निदर्शों के यथोचित अंशशोधन और उनका मूल्यांकन करने के लिए मृदा, मौसम और सस्य विज्ञान के सभी प्रयोगों से प्राप्त होने वाले फ़सल प्रबंधन के व्यापक आँकड़ों के न्यूनतम समूहों को एकत्र करने की आवश्यकता है। इस बात को ध्यान में रखते हुए 1994, 1995, 1996 और 1997 में राजेंद्र नगर (17° 19' उत्तर, 78° 23' पूर्व, 542.3 एम. ए.एम.एस.एल.) में धान की प्रचलित तीन किस्मों नामतः साम्बामसूरी, राजावाडलू, तेलहामसा की फ़सल वाले खेतों में सिंचित परिस्थितियों में प्रयोग किए गए और आँकड़े एकत्र किए गए। सेरेस (सी.ई.आर.ई.एस.) राइस वी 3.5 निदर्श के प्रयोग के लिए आवश्यक आनुवांशिक गुणांकों का परिकलन किया गया और उस क्षेत्र की जलवायु के अनुसार निदर्श के निष्पादन का मूल्यांकन किया गया है। इस अध्ययन से प्राप्त हुए परिणामों से पता चलता है कि फ़सल में फूल आने के समय साम्बामसूरी, राजावाडलू और तेलहामसा के संबंध में निदर्श द्वारा किए गए आकलन में किस्मों के बारे में क्रमशः 6.2, 5.7 और 6.7 दिनों की औसतन त्रुटि पाई गई है। इसी तरह से क्रियात्मक रूप से फ़सल की तीनों किस्मों के पकने की तारीखों के पूर्वानुमान में भी 7.6, 6.7 और 7.2 दिनों की समान त्रुटियाँ पाई गई हैं। फसल की तीनों किस्मों की पैदावार के संबंध में निदर्श के पूर्वानुमानों में भी औसतन क्रमशः 7.9%, 8.3% और 5.7% की त्रुटि पाई गई हैं। इन परिणामों से यह संकेत मिलता है कि आंध्र-प्रदेश की जलवायु की स्थितियों में अनाज की फसल और फसल के घटना विज्ञान के रूप में विकास के बारे में आशानुरूप सही पूर्वानुमान देने में सेरेस राइस वी 3.5 निदर्श सक्षम है और इसीलिए राज्य में कृषि संबंधी योजनाएं तैयार करने से संबंधित विभिन्न प्रकार के नीतिपूर्ण एवं कुशल निर्णय लेने के लिए इस निदर्श के सहायक होने की संभावनाएं हैं।

ABSTRACT. Crop growth simulation models, properly validated against experimental data have the potential for tactical and strategic decision making in agriculture. Such validated models can also take the information generated through site specific experiments and trials to other sites and years. For proper calibration and evaluation of crop simulation models, there is a need for collection of a comprehensive minimum set of data on soil, weather and crop management in all agronomic experiments. Keeping this in view, field experiments were conducted at Rajendranagar (17°19' N, 78°23' E; 542.3 m amsl) during 1994-97 for three popular varieties of rice *viz*. Sambamasuri, Rajavadlu and Tellahamsa under irrigated conditions and data collected. Genetic coefficients required for running the CERES-Rice v3.5 model were calculated and the performance of the model under the climate of the area was evaluated. The results of the study show that the model simulations of date of flowering for Sambamasuri, Rajavadlu and Tellahamsa were within an average error of 6.2, 5.7 and 6.7 days respectively. Similar errors in predictions of physiological maturity dates were 7.6, 6.7 and 7.2 days. The error in grain yield predictions by the model averaged at 7.9%, 8.3%, and 5.7% respectively for the three crop varieties. These results indicate that the CERES Rice v3.5 model is capable of prediction of grain yield and phenological development of the crop in the climatic conditions of Andhra Pradesh with reasonable accuracy and hence, the model have the potential for its use as a tool in making various strategic and tactical decisions related to agricultural planning in the state.

Key words – Crop simulation model, Rice, Genetic coefficients.

1. Introduction

Through crop growth modeling it became possible to simulate a living plant through the mathematical and conceptual relationships which govern its growth in the soil atmosphere continuum. Such a model allows synthesis and mobilization of existing knowledge about individual processes leading to yield of a crop and helps pinpoint deficiencies of knowledge and such a model can calculate crops response to environmental changes (Angus and Zandstra, 1979). The advantages of crop modeling been well illustrated in the works of Nix (1976) and de Wit (1978). The crop growth models developed can be useful in crop management, if phenological stages are accurately simulated in necessary detail needed for practical applications (Miller *et al.*, 1993). Some of the crop management decisions which can be linked to phenology are:

(*i*) Irrigation application which should be made at strategic phenophases to achieve maximum water use efficiency.

(*ii*) Fertilizer application at early, mid and maximum tillering and at panicle initiation.

(*iii*) Herbicide application, which can be based on the leaf stage of the crop as well as the target weeds.

(*iv*) Invertebrate pest control, which must take place prior to a given leaf stage, and

(*v*) Harvest.

Keeping in view the potential of crop simulation models in agricultural research and applications, an attempt has been made in this study to validate the CERES Rice v3.5 model in simulations of crop growth development and yield in the semi-arid climate of Andhra Pradesh in order to utilize the model for optimizing the crop output from farm operations in the state.

Occupying about 8.4% of the country's area Andhra Pradesh forms the fifth largest state in India and supports a population of over 62 million. The state represents a semi-arid climate, with the exception of the coastal areas exhibiting humid to sub-humid climate. Rainfall is received from both southwest and northeast monsoons, averaging about 896 mm annually. A 40% of the gross cropped area and 94.3% area of rice is irrigated in the state. About 77% of the population are engaged in agricultural sector and rice is the staple food. Rice yields average in the state to only about 2490 kg/ha (Directorate of Economics and Statistics, 1997). Studies directed towards understanding the different aspects of rice cultivation in the state which can lead to enhancement of its yield returns is of paramount importance for the improvement of the socio-economic status of the farmers of the state.

The works of Wickham (1973) and Ahuja (1974) clearly show that the yield variation in rice crop production due to weather, management and biotic factors can be addressed through a modeling approach. Later many attempts have been made with different extents of success at developing an ideal weather-dependent model for a rice crop, *e.g.* Angus & Zandstra (1979), Whisler (1983), Iwaki (1975, 1977), Mota & Silva (1979) Bolton & Zandstra (1981a, b), McMennamy (1979), Penning de Vries *et al.* (1989), Miller *et al.* (1993) and Kropff *et al.* (1994 a). CERES (Crop Estimation through Resources and Environment Synthesis) models were the result of an attempt made in the United States of America to produce a user-oriented, general simulation model for various crops; these models predict the performance of a particular cultivar, sown at any time in any climate, which would lead to transfer of agrotechnology information. These models help accomplish this goal by defining a minimum set of soil, weather, management and genetic information that should be collected in practically all field experimental trials to help explain outcomes and, thereby, transfer technology beyond the site and year of the trial. The result of these endeavors was CERES models of barley, maize, millet, sorghum, wheat, and rice; CROPGRO models of dry bean, peanut and soybean; CROPSIM of cassava; and SUSTOR models for aroids and potato (Tsuji *et al.*, 1994). The International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT), incorporated these models into its international programme for agrotechnology transfer and developed DSSAT (Decision Support System for Agrotechnology Transfer) version 2, 3 and 3.5 packages. The first milestone in building a crop growth model for rice for the DSSAT package was crossed with the presentation of the CERES model for upland rice by Alocilja & Ritchie (1988). The CERES-Rice model, as available in DSSAT v3.5 (Hoogenboom *et al.*, 1999), is a growth and development simulations model of the rice crop under upland and lowland conditions. It is a daily time-step model that simulates grain yield and growth components of different varieties in a given agroclimatic condition. The model simulates the transformation of seeds, water and fertilizers into grain and straw through the use of land, energy (solar, chemical and biological) and management practices, subject to environmental factors such as solar radiation, maximum and minimum air temperature, precipitation, day length variation, soil properties and soil water conditions. The model takes into account the nitrogen fertilization and water balance in the soil or irrigation.

Saseendran *et al.* (1998a) evaluated the performance of the CERES Rice v3. For the climatic conditions of the state of Kerala, India and found that in four experiments using different transplanting dates during the virippu (June–September) season under rainfed conditions (*i.e.* no irrigation), the flowering date was predicted within an error of four days and date of crop maturity within an error of two days. Also the grain yield prediction was within an error of 3% for all transplanting dates. Saseendran *et al.* (1998b) utilized the validated and calibrated CERES Rice v3.0 model for deriving the optimum transplanting dates for rice at various locations in Kerala, a monsoon effected state in southern India. The method followed for evolving the optimum transplanting dates can be adopted for use elsewhere if specific weather, soils, and crop information is available. Jintrawet (1995) used the CERES-Rice model to develop a decision-support system for the fast assessment of rice-cropping alternatives in lowland areas of Thailand. The system that evolved caters for the decision making at the farm and policy levels; it comprises of the model validated for the area of interest and an analytical tool for answering several 'what if' questions. The study demonstrated that the CERES-Rice model is able to simulate low yields obtained by farmers in northeast Thailand and the relatively higher yields in northwest Thailand. The study also proved the validity of the model in finding alternative ways to improve farm performance with regard to rice production. The CERES Rice v3. crop simulation model, calibrated and validated for its suitability to simulate rice production of an area can also be used for analysing the effect of climate change on rice productivity in the area (Saseendran *et al.*, 2000).

In light of the high potential of the well calibrated and validated crop simulation models for solving problems in strategic and tactical decision makings in agriculture, field experiments were carried out at the Agricultural Research farm, Rajendranagar, Hyderabad during two crop seasons each of 1994, 1995, 1996 and 1997 for three popular varieties of rice *viz.* Sambamasuri, Rajavadlu and Tellahamsa under irrigated conditions to collect the minimum data required for derivation of the genetic coefficients for running the CERES-Rice v3.5 model and also to validate its performance in the climate of the area. Results of the study are presented in this paper.

2. Material and methods

2.1. *The model*

The CERES-Rice version 3.5 (Hoogenboom *et al.*, 1999) model was used in the present study. In this model, the following processes are simulated on a daily basis.

(*i*) Phenological development of the crop as the genetic characters of the crop variety effect it and weather.

(*ii*) Growth of leaves, stems and roots.

(*iii*) Biomass accumulation and partitioning among leaves, stem, panicle, grain and roots.

(*iv*) Soil water balance and water use by the crop.

(*v*) Soil nitrogen balance and uptake by the crop.

Also, the phenological stages *viz.* sowing to transplantation, germination of seeds, emergence, juvenile phase, panicle initiation, heading, beginning and end of grain filling and physiological maturity are simulated by the model.

Simulation of the duration of each phenological stage uses the concept of thermal time or degree-days and photoperiod as defined by the genetic characteristics of the crop. Employing a carbon balance approach in a source-sink system simulates crop growth. The analytical relationships of the soil water balance and nitrogen transformation and uptake leading to the quantification of these stress factors are presented by Jones & Kiniry (1986). The daily rate of gross photosynthesis (*W*) is calculated for the rice crop canopy as a function of daily accumulated solar radiation, day length, extinction coefficient of light within canopy, light transmissibility of single leaf at light saturation and the leaf area index.

A portion of the carbohydrate synthesized, termed the net photosynthate, is used in the synthesis of plant tissue and the rest is used in respiration to maintain the existing tissue. The net photosynthate produced is shared between the shoot and root. The shoot biomass is partitioned further between leaf, stem, panicle and grain, according to the functional relations, which govern these partitioning at different growth stages. For a detailed description of the model structure and initial validation [Alocilja & Ritchie (1988) and Alocilja (1987)]. It is important to note that, like in the building of any other crop simulation model, this model is also built on certain assumptions. Weeds, insects and diseases are assumed

TABLE 1

Genetic coefficients used in the CERES-Rice simulation model

Name	Description
Development aspects	
Juvenile phase coefficient (P1)	Time period (expressed as growing degree-days [GDD] in °C over a base temperature of 9°C) from seeding emergence during which the rice plant is not responsive to changes photoperiod. This period is also referred to as the basic vegetative phase of the plant.
Critical photoperiod (P2O)	Critical photoperiod or the longest day length (in hours) at which the development occurs at a maximum rate. At values higher than P2O development rate is slowed, hence there is delay due to longer day lengths.
Photoperiodism coefficient (P2R)	Extent to which phasic development leading to panicle initiation is delayed (expressed as GDD in ° C) for each hour increase in photoperiod above P2O.
Grain filling duration coefficient (P5)	Time period in GDD (° C) from beginning of grain filling (3 to 4 days after flowering) to physiological maturity with a base temperature of 9° C.
Growth aspects	
Spikelet number coefficient (G1)	Potential spikelet number coefficient 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.
Single grain weight (G2)	Single grain weight (gram) under ideal growing conditions, *i.e.* non-limiting light, water, nutrient and absence of pests and diseases.
Tillering coefficient (G3)	Tillering coefficient (scaler value) relative to IR64 cultivar under ideal conditions. A higher tillering cultivar would have coefficient greater than 1.0.
Temperature tolerance coefficient (G4)	Temperature tolerance coefficient. Usually 1.0 for varieties growth 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.

fully controlled by the administration of appropriate remedial measures from time to time. Efforts are already underway to couple pest models to crop models for predicting the reduction in yield caused by them (Boote *et al.*, 1983, 1993; Pinnschmidt *et al.*, 1995). Except for nitrogen, it is assumed that there is no nutrient deficiencies or toxicities. The damaging effects of catastrophic weather events and problematic soils are not taken into account in the model. With these limitations, the CERES-Rice model simulates the effects of weather, cultivar, management practices, soil water and nitrogen fertilizer on rice growth and yield (Alocilja & Ritchie, 1988).

2.2. *Input and output requirements*

The model requires a set of minimum data pertaining to weather, soil, genotype characteristics and crop management details to run. These data are provided to the model through data files. The different input data requirements are described in the sections following this paragraph. In addition to these, the experiment performance data is also used as input, if the simulated results are to be compared with data recorded in a particular experiment. To run the model, a file containing information about all the available experiments is provided to the model.

2.2.1. *Weather data file*

Daily weather data on maximum temperature, minimum temperature, total solar radiation and rainfall for the crop period are required for the simulation.

2.2.2. *Soil data file*

Values of soil albedo, upper limit of stage 1 cumulative evaporation, the soil water conductivity factor and the runoff curve number are required and soils are described by layer including the depth of each layer. The lower and upper limits of plant extractable water, saturated soil water content and root distribution function are the most essential parameters needed for running the model.

2.2.3. *Cultivar data file*

Eight cultivar specific genetic coefficients are required for describing the various aspects of performance of a particular genotype in the model. They are given in Table 1.

2.2.4. *Experiment details file*

This contains the details of all inputs (observed field data) to the models for each simulation (Table 2).

TABLE 2

Experimental details required for running the model

Type of information	Details of information
Field characteristics	Weather station name, soil and field description details
Soil analysis data	Soil properties used for the simulation of nutrient dynamics, based on filed nutrient sampling, if any
Initial soil water and inorganic nitrogen conditions	Starting conditions for water and nitrogen in the profile and also used for root residue carry over from the previous crop and N symbiosis initial conditions when needed
Seedbed preparation and planting geometries	Planting date, population, seeding depth and row spacing data
Irrigation and water management	Irrigation dates, amounts, thresholds and rice flood water depths
Fertiliser management	Fertiliser date, amount and type information
Organic residue application	Additions of straw, green manure, animal manure
Chemical applications	Herbicide and pesticide application data
Tillage operations	Dates and types of tillage operations
Environmental modifications	Adjustment factors for weather parameters as used in climate change and constant environment studies (*e.g.* constant day length, shading, constant temperature)
Harvest management	Harvest dates and plant components harvested
Specification of simulation options	Starting dates
On/off options for model components	Water and nitrogen balances
Output options	

TABLE 3

Genetic coefficients developed for crop varieties *viz*. Sambamashuri, Rajavadlu and Tellahamsa in the agroclimatic conditions of Andhra Pradesh

Growth and development aspects of the rice crop	Genetic coefficients for Sambamasuri	Genetic coefficients for Rajavadlu	Genetic coefficients for Tellahamsa
Development aspects			
Juvenile phase coefficient (P1)	540	390	200
Photoperiodism coefficient (P2R)	170	160	140
Grain filling duration coefficient (P5)	400	400	350
Critical photoperiod (P2O)	12	12	12
Growth aspects			
Spikelet number coefficient (G1)	100	90	100
Single grain weight (G2)	0.022	0.025	0.022
Tillering coefficient (G3)	1.00	1.00	1.00
Temperature tolerance coefficient (G5)	1.00	1.00	1.00

2.2.5. *Experiment performance file*

This contains observed values of experimental performance of the crop, which can be used for comparison with the simulated outputs of the model runs. The information provided includes anthesis date, physical maturity, yield, grain weight, grain number, ear number, maximum LAI and dry matter.

2.3. *Output files*

Six output files are produced by the model runs namely overview, summary, growth, carbon, water and nitrogen. The output file, OVERVIEW, provides an overview of input conditions and crop performance and a comparison with the actual data if available. The second output file, SUMMARY, provides a summary of output

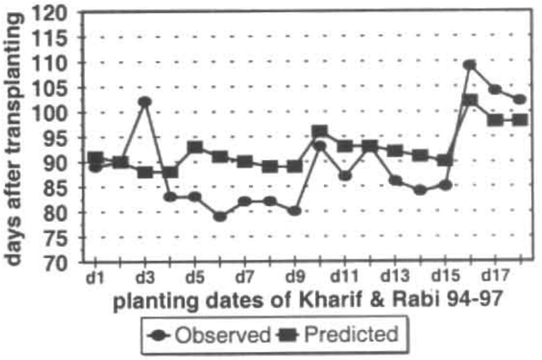

Fig.1. Comparison of observed and simulated flowering time - Sambamasuri

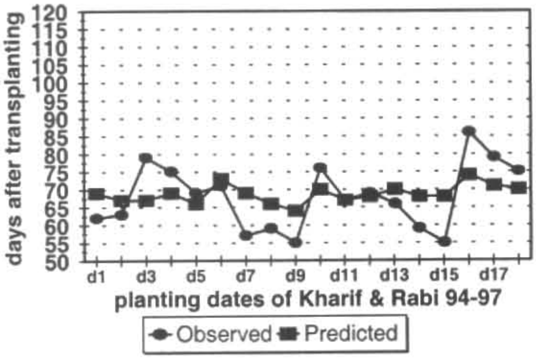

Fig.3. Comparison of observed and simulated flowering time - Tellahamsa

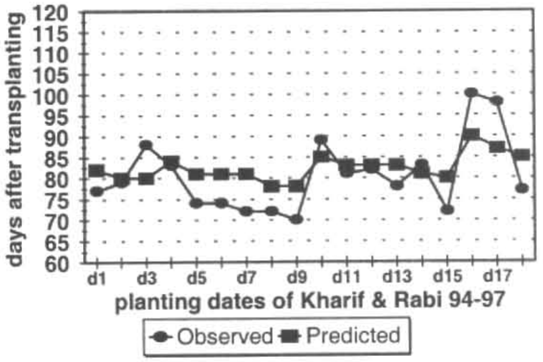

Fig.2. Comparison of observed and simulated flowering time - Rajavadlu

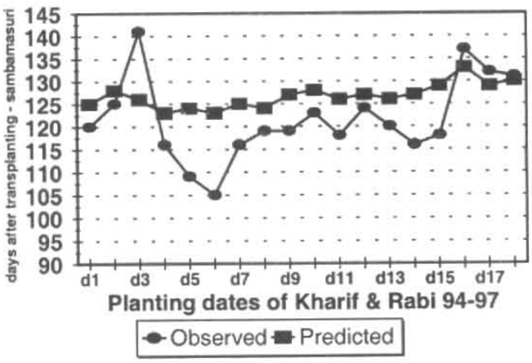

Fig.4. Comparison of observed and simulated physiological maturity time - Sambamasuri

for use in application programmes. The remaining four files (GROWTH, CARBON, WATER and NITROGEN) contain detailed simulation results including growth and development, carbon balance, water balance and nitrogen balance.

2.4. *Materials for the present study*

Field experiments were conducted at the research farm of the Regional Research Institute, Rajendranagar, Hyderabad (17° 19' N, 78° 23' E and 542.3 m above mean sea level) on sandy loam soil during Kharif (June to September/October) and Rabi (December to March/April) seasons of 1994, 1995, 1996 and 1997. The experiment was laid out in a Randomized block design (factorial) with three dates of plantings and three varieties replicating thrice. The eighteen planting dates thus adopted were 13 July 1994 (D_1); 27 July 1994 (D_2); 13 August 1994 (D_3); 11 January 1995 (D_4) ; 25 January 1995 (D_5); 4 February, 1995 (D_6); 10 July, 1995 (D_7); 25 July, 1995 (D_8); 13 August, 1995 (D_9); 27 December 1995 (D_{10}); 17 January 1996 (D_{11}); 27 January 1996 (D_{12}); 13 July, 1996 (D_{13}); 27 July 1996 (D_{14}); 13 August 1996 (D_{15}); 11 January 1997 (D_{16}); 25 January, 1997 (D_{17}); 4 February 1997 (D_{18}); The dates of plantings taken up in kharif and rabi seasons allowed different phases of the three varieties to pass through varying weather conditions. The rice crop varieties used in the experiment are Sambamasuri, a long duration (140 to 145 days) and photo period sensitive, Rajavadlu, a medium duration (130-145 days) and weakly photoperiod sensitive and Tellahamsa, a short duration (105-110 days) and strictly photo-insensitive.

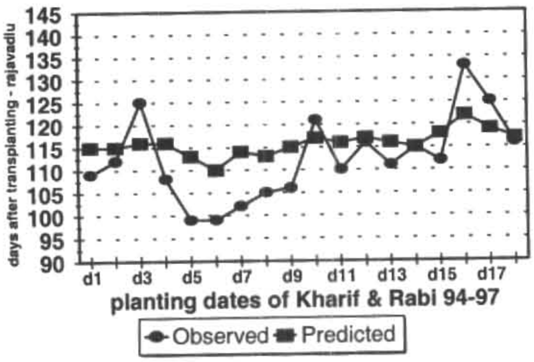

Fig. 5. Comparison of observed and simulated physiological maturity time - Rajavadlu

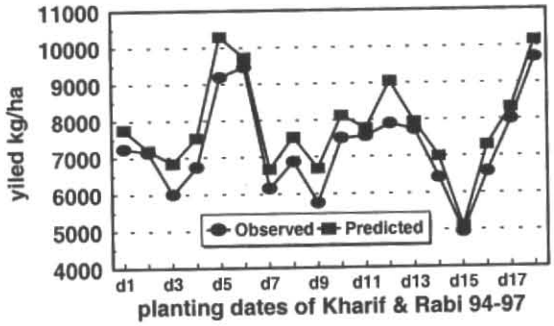

Fig. 7. Comparison of, observed and simulated grain yield of Sambamasuri

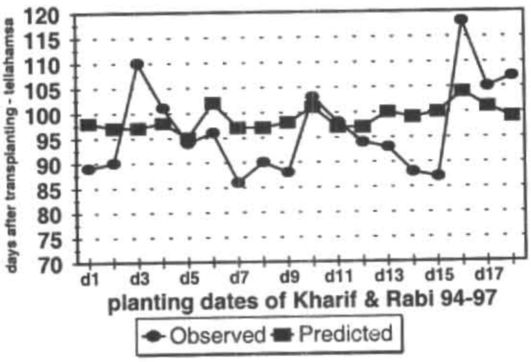

Fig. 6. Comparison of observed and simulated physiological maturity time - Tellahamsa

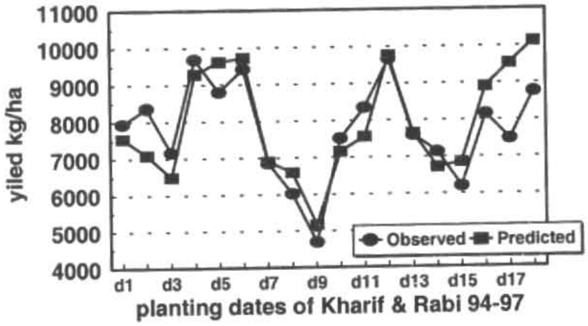

Fig. 8. Comparison of observed and simulated grain yield of Rajavadlu

The same crop management practices were followed in all the experiments. Plant density was maintained at 130 plants / m^2. 120 kg/ha nitrogen fertilizer was applied in three split doses *viz.* 30 kg/ha at two days after transplanting, 60 kg/ha at 15 days after the first dose and 30 kg/ha at 45 days after the second dose. 60 kg/ha each of phosphorous fertilizer was also applied alongwith the nitrogen doses. The farm field was bunded 15 cm high and a constant water level of 5 cm was maintained by flood irrigation.

The daily weather data used was the maximum temperature (at 4.5 ft), minimum temperature (at 4.5 ft), solar radiation and rainfall collected at the experiment station in an ordinary agrometeorological observatory during the experiment's period.

3. Discussion of results

Eight genotype specific coefficients are required for running the CERES Rice v3.5 model. A genetic coefficient calculator (Gencalc) was developed to facilitate determination of the genotype specific coefficients that are used by the IBSNAT crop models (Hunt *et al.*, 1993). Genetic coefficients required in the model for the genotypes Sambamasuri, Rajavadlu, and Tellahamsa were calculated using the Gencalc. Table 3 gives the genetic coefficients calculated for the three cultivars using the crop performance data for the 13 July 1994 transplanting date. Between cultivars the maximum difference is noticed in the Juvenile Phase coefficients, which are 540, 390 and 200 GDD (Growing Degree-Days) respectively for genotypes Sambamasuri, Rajavadlu, and Tellahamsa. In general, it was found that though coefficients for other development aspects vary to some extent for these varieties but there is hardly any variation in the coefficients for growth aspects. The coefficients presented in the table are used for further validation of the model for the rest of the transplanting dates in 1994, 1995, 1996 and 1997. The observations of the model runs are given in the following paragraphs.

Predictions of different phenological stages of the crop are crucial because at different critical stages of growth of the plant, for instance at flowering, it is essential to ensure that the crops do not suffer from moisture and fertiliser stresses. Also, good prediction on the date of maturity can help the farmer to plan for harvesting and marketing his crop. A reasonably validated model for its phenological predictions, can be utilised for advising the farmer to plan and optimize his farm operations for better outputs. Figs. 1 to 3 present comparisons between field observed and CERES-Rice model simulated phenological occurrence of flowering dates of the three cultivars *viz.* Sambamasuri, Rajavadlu, and Tellahamsa in days after transplantation of 18 transplanting dates repeated in the years 1994, 1995, 1996 and 1997. The results obtained in the analyses show that the percentage departures of flowering date predictions from observed dates were between –9% and 13%, –11% and 11%, and –21% and 15% respectively for the three rice varieties. On average, the departures of flowering time predictions from observed were 6.2, 5.7 and 6.7 days respectively.

Figs. 4 to 6 present the performance of the dates of physical maturity simulations of the model in relation to those observed in the experimental field for three rice varieties *viz.* Sambamasuri, Rajavadlu, and Tellahamsa in the 18 transplanting dates. Averaged over the transplanting dates, the errors of the simulations from observed were seen to be 7.6, 6.7 and 7.2 days respectively for the three cultivars and the percentage deviations varied between –13% to 10%, –14% to 8%, –14% to 11%.

Results of the phenology simulations of the model show that they are only accurate enough to take broad scale planning of cultural operations in the field, notwithstanding the higher accuracy requirement for day-to-day tactical decision making at the farmers field level.

Figs. 7 to 9 present comparisons of the grain yield predictions of the model with the observed, for the eighteen experiments with different transplanting dates for the three rice varieties under study. The results show that the grain yield predictions by the model were within an average error of 7.9% for Sambamasuri, 8.3% for Rajavadlu and 5.7% for Tellahamsa in 18 transplanting date replications of the experiment. The percentage deviations of model simulations of grain yield from observed were –0.76% to –16.33%, 15.14% to –27.39% and –21.97% to 11.65% respectively.

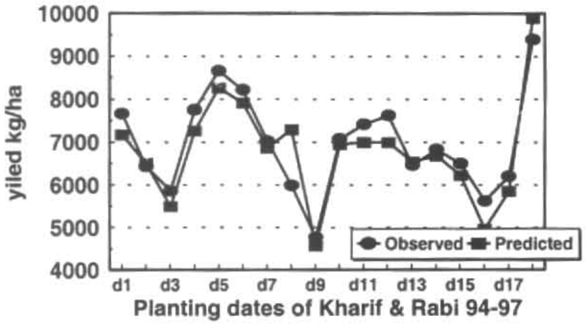

Fig. 9. Comparison of observed and simulated grain yield of Tellahamsa

The high accuracy of the grain yield prediction shows the ability of the model to simulate the growth of the crop in the semi-arid climatic conditions of the state of Andhra Pradesh under irrigated conditions with unlimited water supply. In this context, it may be noted that the yield prediction of the rice crop is crucial for the economic planning in the state.

4. Conclusions

Genetic coefficients required for the CERES-Rice v3.5 model for simulation of the growth and development of rice crop have been derived for three rice cultivars *viz.* Sambamasuri, Rajavadlu, and Tellahamsa, under the climatic conditions of the state of Andhra Pradesh, India. The model simulations were subsequently validated against observed data from field experiments. The model was found to be able to predict the phenological occurrence of the crop well enough to help the farmers to make broad scale decisions on the crop management operations which can be directly linked to crop phenology. The better ability of the model in simulating total grain yield of the crop would enable the policy makers and planners on taking agriculture based economic decisions in the state. It is envisaged that the validated model would provide insights for rice crop physiologists and agronomists about the response mechanisms to various weather/climate conditions.

Also, it can be concluded that the modelling of rice crop yield using CERES-Rice v3.5 is accurate enough to be considered a reasonably reliable tool for use in climate risk assessment studies in agriculture. Reasonably validated models can replace much of the trial and error type methods in agricultural research. It is essential to make available to the low-yielding rice growing places the Agrotechnology developed at the experimental stations and high-yielding fields. The conventional research/demonstration method of transferring new technologies from one place to another takes time and money. Once a model has been developed, calibrated and tested to the stage that it accounts for the major yield factors in a region, the model can be made part of the whole system of regional agricultural research by adopting a system frame-work for the crop and agrometeorology data collection. To apply a model this way there is a need for a regional experimental programme to collect a balanced set of data about the crop, environmental and weather with which the model can be used. These models have the potential for use in defining areas and landscape positions suitable for raising the rice crop as well as multiple cropping. Uncertainty about the accuracy of solar radiation, extractable soil water, initial water and nitrogen status in the soil are some of the frequently encountered problems in crop model validity and calibration and the models currently available lack demonstrated strengths in assessing risk related to pests, diseases, tillage and nutrients other than nitrogen.

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