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# Evaluation of the CERES-Rice version 3.0 model for the climate conditions of the state of Kerala, India

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*The CERES-Rice version 3.0 crop growth simulation model was calibrated and evaluated for the agroclimatic conditions of the state of Kerala in India. Genetic coefficients were developed for the rice crop variety Jaya and used for the model evaluation studies. In four experiments using different transplanting dates during the virippu season (June to September) 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. The model was found to predict the phenological events of the crop fairly well. The grain yield predicted by the model was within an error of 3% for all the transplanting dates, but the straw yield prediction was within an error of 27%. The high accuracy of the grain yield prediction showed the ability of the model to simulate the growth of the crop in the agroclimatic conditions of Kerala. It can be concluded from this study that the model can be used for making various strategic and tactical decisions related to agricultural planning in the state.*

## 1. Introduction

Mankind's achievements in attempting to predict various natural phenomena allow future operations to be planned and provide the opportunity for making profits. Modelling crop behaviour from weather and management practices is an example of this kind of scientific endeavour. The advantages of crop modelling were well illustrated in the works of Nix (1976) and de Wit (1978). Crop production involves a complex interaction between crop genotype, the soil and the aerial environment, and crop management practices. Information generated about the various components of the production system and their interactions has been used to develop crop simulation models. These models have the potential of taking agricultural research and development into the age of fast information technology.

The crop growth models developed can be useful in crop management, if phenological stages (i.e. development stages of the crop in relation to weather) are accurately simulated in sufficient detail for practical applications and management strategies. But linking the schedule of management action with the details of the phenological and morphological (i.e. form and structure of the organs, e.g. leaf area) development of the plant is a prerequisite for this. According to Miller *et al.* (1993), the management decisions that can be directly linked to crop phenology are as follows:

(a) Irrigation application that should be made at strategic phenological stages to achieve maximum water use efficiency.
(b) Fertiliser application that can be based on tissue analysis at early, mid- and maximum tillering (i.e. side-shoot growth from the base of the stem) and at panicle (i.e. inflorescence or flower bunch) initiation.
(c) Herbicide application, which can be based on the leaf stage of the crop and also the target weeds.
(d) Invertebrate pest control, which must take place before a given rice leaf stage.
(e) Harvest.

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 modelling approach. This work was followed by many other attempts 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 (1989), Miller *et al.* (1993) and Kropff *et al.* (1994).

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 endeavours 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 of 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) versions 2 and 3 packages (Tsuji *et al.*, 1994).

The CERES model for upland rice was presented by Alocilja & Ritchie (1988). The CERES-Rice model (Singh *et al.*, 1994), as available in DSSAT v3. (Tsuji *et al.*, 1995), 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 fertilisers 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 fertilisation and water balance in the soil or irrigation.

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 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 north-east Thailand and the relatively higher yields in north-west Thailand. The study also proved the validity of the model in finding alternative ways to improve farm performance with regard to rice production.

Keeping in view the potential of the crop simulation models for tactical and strategic decision making in agriculture, in this study an attempt has been made (a) to generate genetic coefficients for *Jaya*, one of the commonly used rice crop varieties in the state, and (b) to evaluate the CERES-Rice version 3.0 model for crop growth simulation in the state of Kerala.

## 2. The model

In this study, the CERES-Rice version 3.0 model (Singh *et al.*, 1994) was used. The various processes simulated by this model are listed in Table 1 and the phenological stages simulated by the model are given in Table 2. 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.

Crop growth is simulated by employing a carbon balance approach in a source-sink system. Photosynthesis is the process whereby the plant converts intercepted light into carbohydrates. It is initially assumed to be controlled only by solar radiation and temperature, and later modified by the effect of stresses due to temperature, water and fertiliser. 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

Table 1. *Processes simulated by the CERES version 3.0 model*

| Processes developed on a daily basis |
|---|
| Phenological development of the crop as it is effected by the genetic characters of the crop variety studied and weather |
| Growth of leaves, stems and roots |
| Biomass accumulation and partitioning among leaves, stem, panicle, grains and roots |
| Soil water balance and water use by the crop |
| Soil nitrogen transformations and uptake by the crop |

Table 2. *Phenological stages simulated by the model*

| |
|---|
| Sowing or transplantation |
| Germination (if the crop was sown) |
| Emergence (if the crop was sown) |
| Juvenile phase |
| Panicle initiation |
| Heading |
| Beginning of grain filling |
| End of grain filling |
| Physiological maturity |

leaf at light saturation and the leaf area index. The equation used is as follows:

$$\frac{dW}{dt} = RUE.R_{par} \frac{(1 - e^{-kLAI})}{POP} T_f W_f$$

where *RUE* is the radiation use efficiency of the rice crop, *POP* is the plant population density, $T_f$ is the temperature stress compensation factor, $W_f$ is the soil moisture stress compensation factor, $R_{par}$ is the photosynthetically active radiation, *k* the light extinction coefficient within the canopy, and *LAI* the leaf area index.

Leaf area expansion in the model is taken to be a function of leaf growth at a particular time and the number of leaves per plant at that time, which in turn is calculated using the phyllochron concept. Leaf expansion is also taken as a function of the plant's genetic characteristic for tillering. The conversion factor is 0.037 $m^2$ leaf expansion per leaf per gram of leaf growth. *LAI* is calculated from the total leaf area generated.

A portion of the carbohydrate synthesised, termed the net photosynthate, is used in the synthesis of plant tissue and the rest is used in respiration to maintain the existing tissue (Jones *et al*., 1987). 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 that govern these partitioning at different growth stages.

The tillering growth in the model is taken as a function of the number of leaves per plant emerging at a particular time, the fraction of carbohydrates going to the leaves at that time, the plant's genetic characteristic for tillering, and a tillering population factor.

For a detailed description of the model structure and initial validation see Alocilja & Ritchie (1988) and Alocilja (1987). It is important to note that, as with the construction of any other crop simulation model, this model is also built on certain assumptions. Weeds, insects and diseases are assumed fully controlled by the administration of appropriate remedial measures from time to time. Except for nitrogen, it is assumed that there are 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 fertiliser on rice growth and yield (Alocilja & Ritchie, 1988).

The primary thrust of the models developed so far is to analyse how weather and genetic characteristics affect potential yield given a specified management scheme. The factors currently given attention are limited to plant water supply and plant nitrogen supply. It is assumed that the nutrient factors representing phosphorus, potassium and other essential plant nutrients are in abundant supply in the soil so as not cause any stress to the plant; hence consideration of these factors is excluded. The pest problems, weeds, diseases, and toxicities of the soil as well as soil salinity and soil erosion problems are also not covered by the model. 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).

## 3. Input and output requirements

An overview of the input and output files used by the model is given in Figure 1.

### 3.1. Input files

The input data files required for running the model pertain to weather, soil, genotype characteristics (crop and cultivar) and experiment details (crop management). In addition to the above, the experiment performance file 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 (labelled *EXP.LST* in Figure 1). During the model execution, this experiment list would appear as a menu from which the user can select an experiment for simulation. The different input files are as follows.

(a) *Weather data file (FILEW).* This contains daily weather data on maximum temperature, minimum temperature, total solar radiation and rainfall for the crop period.
(b) *Soil data file (FILES).* This contains soil information about all the sites encountered by CERES. To run the model one can either select a representative soil description from this file or simply add soil information to this file as needed. Soils are identified by a soil number. For each soil the values of soil albedo, the upper limit of stage 1 cumulative evaporation, the soil water conductivity factor and the runoff curve number are given. 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 out of all the information provided available.
(c) *Cultivar data file (FILEC).* This file contains the cultivar specific coefficients. Eight genetic coefficients are required for describing the various aspects of performance of a particular genotype. They are given in Table 3.
(d) *Experiment details file (FILEX).* This contains the inputs (observed field data or hypothetical one) to the models for each simulation (see Table 4).

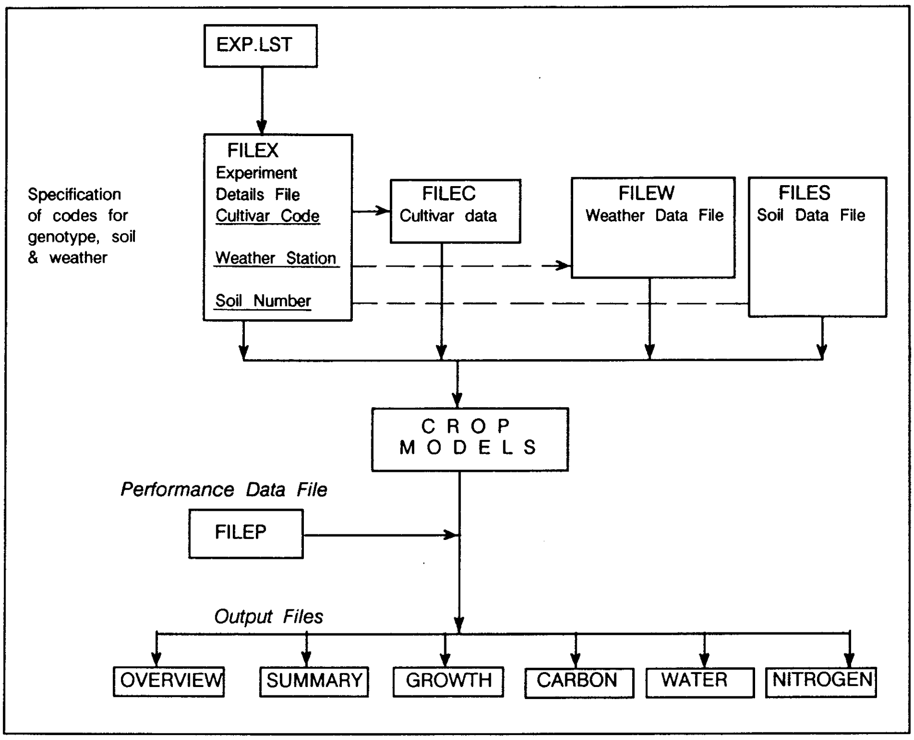


Figure 1. *Overview of input and output files*

(e) *Experiment performance file (FILEP).* 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.

## 3.2. Output files

The model run produces six output files. 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 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.

## 4. Materials for the present study

The rice crop variety *Jaya* has been selected for this study as it is one of the popularly cultivated cultivars in Kerala during the *virippu* season (June to September/October) under rainfed conditions. The performance data of the *Jaya* rice from the Regional Research Station, Kerala Agricultural University, Pilicode (12° 12' N, 75° 10' E) in the 1993 and 1994 *virippu* season have been used for evaluation of the model. The crop management details of the experiment are given in Table 5.

The daily weather data used was the maximum temperature (at 4.5 ft), minimum temperature (at 4.5 ft), hours of bright sunshine and rainfall collected at the experiment station (Pilicode) in an ordinary agrometeorological observatory during the experiment's period. The incoming solar radiation ($R_S$) was calculated indirectly from the number of sunshine hours, using the Angstrom standard formula:

$$R_s = \left(a + \frac{bn}{N}\right) R_A$$

where $R_A$ is the theoretical amount of radiation that would reach the earth's surface in the absence of the atmosphere, $n$ is the actual duration of sunshine hours, $N$ is the maximum possible duration of sunshine and $a$ and $b$ are constants.

The soil type in which is rice is gown in the state of Kerala is mainly Sandy Clay Loam. Relevant data for this soil type is used in the model validation studies.

## 5. Discussion of results

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 genotype *Jaya* were cal-

Table 3. *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 in 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 owing 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 (3–4 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 (g) under ideal growing conditions, i.e. non-limiting light, water, nutrients, and in the 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 a 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. |

Table 4. *Content of the experimental details file (FILEX)*

| 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, and 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 | E.g. harvest dates and plant components harvested |
| Specification of simulation options | E.g. starting dates |
| On/off options for model components | E.g. water and nitrogen balances |
| Output options | |

Table 5. *Crop management details for the experiment*

| Parameter | Choice |
|---|---|
| Cultivar | *Jaya* |
| Transplanting date | 8, 15, 22 and 29 June 1993 and 1994 |
| Plant density | 99.0 $m^{-2}$ |
| Row spacing | 20 cm |
| Soil | Shallow sandy loam |
| Fertiliser | 200 kg $ha^{-1}$ urea in two applications, one basal and another one at the time of maximum tillering stage |
| Irrigation | Unirrigated (rainfed) |

culated using Gencalc. The coefficient for the IR8 cultivar was taken as the starting assumption for the calculation. The coefficients calculated for the cultivar using the crop performance data for the 8 June transplanting date are presented in Table 6. It can be seen from the table that except for the single grain weight and tillering coefficient, all the other coefficients differ greatly from their assumed values for the *IR8* cultivar. The coefficients presented in the table are used for further validation of the model for three more transplanting dates in 1993 (15, 22 and 29 June) and four transplanting dates in 1994 (8, 15, 22 and 29 June). The results obtained are described in the following paragraphs.

Table 7 presents a comparison between the CERES-Rice model simulated and the observed phenological occurrence of heading date and physiological maturity date in days after transplantation in four transplanting dates repeated in 1993 and 1994 at Pilicode (Regional Research Station, Kerala Agricultural University, Trichur, Kerala, India). The results show that the flowering date was predicted by the model with an error of 1 day, 4 days, 3 days and 2 days for the 8 June, 15 June, 22 June and 29 June transplanting dates respectively in the year 1993. The corresponding errors for 1994 were 4, 6, 7 and 5 days. For the predictions of the date of maturity, it can be seen from Table 7 that the predictions for all eight transplanting dates were within an error of 6 days. These results show that with the help of the genetic coefficients derived for the *Jaya* rice variety in the state of Kerala, the model is able to predict the phenology of the crop with fairly good accuracy. These predictions are crucial because at flowering it is essential to ensure that the crops do not suffer from moisture and fertiliser stress. Also, the good prediction on the date of maturity can help the farmer to plan for harvesting and marketing his crop. As such, the validated CERES-Rice version 3.0 model can be utilised to advise the farmer to plan and optimise farm operations.

Table 6. *Genetic coefficients developed for the crop variety Jaya in the agroclimatic conditions of Kerala*

| Growth and development aspects of the rice crop | Genetic coefficients for *Jaya* | Genetic coefficients for *IR8* |
|---|---|---|
| *Development aspects* | | |
| Juvenile phase coefficient | 830.0 | 880.0 |
| Critical photoperiod | 15.0 | 12.1 |
| Photoperiodism coefficient | 50.0 | 52.0 |
| Grain-filling duration coefficient | 277.0 | 550.0 |
| *Growth aspects* | | |
| Spikelet number coefficient | 72.8 | 65.0 |
| Single grain weight | 0.028 | 0.028 |
| Tillering coefficient | 1.0 | 1.0 |
| Temperature tolerance coefficient | 1.1 | 1.0 |

Table 8 presents a comparison of the straw and grain yield predictions of the model with the observed, for the eight experiments discussed above. It shows that the grain yield prediction by the model is within an error of 3% for all the transplanting dates. The straw yield prediction was found to be within an error of 17%. The high accuracy of the grain yield prediction shows the ability of the model to simulate the growth of the crop in the agroclimatic conditions of Kerala. In this context, it may be noted that the yield prediction of the rice crop is crucial for the economic planning in the state.

In Table 9, the simulated crop and soil status at different developmental stages of the crop are shown for the model simulation for the 8 June 1993 transplanting date. The table shows that 2740 mm of rainfall was received during the crop growth period, against an evapotranspiration (ET) requirement of 637 mm. Nonetheless, the crop experienced moderate soil moisture stress during the panicle initiation and heading stages, owing to the uneven distribution of rainfall. This indicates the necessity of harnessing the excess water during the rainy period to cater for the need during the lean periods.

Table 7. *Comparison between predicted and observed phenological occurrence of Jaya for different transplanting dates under rainfed conditions ( O = observed; S = simulated)*

| Transplanting date | Heading date (days after transplantation) | | Physiological maturity (days after transplantation) | |
|---|---|---|---|---|
| | O | S | O | S |
| 8 June 1993 | 77 | 76 | 117 | 117 |
| 15 June 1993 | 79 | 75 | 121 | 120 |
| 22 June1993 | 77 | 74 | 122 | 124 |
| 29 June 1993 | 75 | 77 | 120 | 123 |
| 8 June 1994 | 75 | 79 | 110 | 116 |
| 15 June 1994 | 71 | 77 | 111 | 117 |
| 22 June1994 | 80 | 87 | 105 | 111 |
| 29 June 1994 | 78 | 83 | 118 | 122 |

Table 8. *Comparison between predicted and observed growth performance of Jaya under rainfed conditions for different transplanting dates (O = observed; S = simulated)*

| Transplanting date | Grain yield (kg ha$^{-1}$) | | Weight per grain (g) | | Grain number (grain m$^{-2}$) | | Straw weight at harvest (kg ha$^{-1}$) | |
|---|---|---|---|---|---|---|---|---|
| | O | S | O | S | O | S | O | S |
| 8 June 1993 | 5 100 | 5 089 | 0.030 | 0.030 | 16 413 | 15 135 | 4 600 | 7 758 |
| 15 June 1993 | 5 300 | 5 312 | 0.030 | 0.028 | 18 735 | 16 315 | 5 100 | 7 184 |
| 22 June 1993 | 4 300 | 4 160 | 0.030 | 0.028 | 18 565 | 17 786 | 4 500 | 6 213 |
| 29 June 1993 | 3 300 | 3 267 | 0.030 | 0.029 | 16 251 | 14 679 | 4 200 | 6 743 |
| 8 June 1994 | 5 200 | 5 380 | 0.029 | 0.029 | 20 520 | 19 989 | 4 900 | 5 900 |
| 15 June 1994 | 5 800 | 5 855 | 0.030 | 0.030 | 21 158 | 21 892 | 5 000 | 6 900 |
| 22 June 1994 | 6 250 | 6 600 | 0.029 | 0.030 | 20 358 | 20 099 | 5 300 | 5 400 |
| 29 June 1994 | 6 500 | 6 760 | 0.030 | 0.030 | 21 899 | 21 900 | 5 800 | 5 200 |

Table 9. *Simulated crop and soil status at main development stages for 8 June 1993 transplanting (all values cumulative except stress factors)*

| Date | Growth stage | Biomass (kg ha$^{-1}$) | LAI | Leaf number | ET (mm) | Rain (mm) | Nitrogen stress | Water stress |
|---|---|---|---|---|---|---|---|---|
| 8 June | Transplant | 59 | 0.42 | 4 | 50 | 280 | 0.00 | 0.00 |
| 1 August | End juvenile | 3594 | 6.63 | 11 | 306 | 2094 | 0.00 | 0.03 |
| 8 August | Panicle initiation | 4892 | 7.72 | 12 | 348 | 2123 | 0.00 | 0.28 |
| 12 September | Heading | 9409 | 6.19 | 20 | 529 | 2571 | 0.00 | 0.49 |
| 21 September | Begin grain fill | 10725 | 4.26 | 20 | 620 | 2590 | 0.49 | 0.06 |
| 4 October | End grain fill | 12135 | 2.03 | 20 | 631 | 2735 | 0.47 | 0.00 |
| 7 October | Maturity | 12135 | 1.38 | 20 | 637 | 2740 | 0.00 | 0.00 |
| 7 October | Harvest | 12135 | 1.38 | 20 | 637 | 2740 | 0.00 | 0.00 |

In addition to the results presented above, an attempt has also been made to derive the potential yield of the rice crop variety *Jaya* in the state of Kerala in the absence of water and fertiliser related stresses (Table 10). The simulation for the potential yield was made using the weather data for the period 1960 to 1992. Separate runs were made for the four transplanting dates (8, 15, 22 and 29 June). It can be seen from the table that the simulated potential yields based on all the four transplanting dates are above 15 000 kg ha$^{-1}$ with an average of 15 374 kg ha$^{-1}$ with a standard deviation of 537 kg ha$^{-1}$ in the 132-year run. It can be noted at this stage that the observed yield in eight transplanting dates (Table 8) in the years 1993 and 1994 under rain-fed conditions for the existing nutrient management conditions average only to about 5 218 kg ha$^{-1}$. This shows that there exists a wide margin between the achieved yields under rainfed conditions and the achievable yield ( potential) in the state. These results also indicate the need for harnessing and storing the surplus rainwater during the rainy seasons for irrigating the crops during the non-rainy periods, with the aim of achieving optimum yield potential for the area.

Table 10. *Potential yield predicted by the model for during the period 1960–1992 of the rice variety Jaya for four transplanting dates*

| Transplanting date | Potential yield | |
|---|---|---|
| | Mean (kg ha$^{-1}$) | Standard deviation (kg ha$^{-1}$) |
| 8 June | 15680 | 502 |
| 15 June | 15488 | 531 |
| 22 June | 15289 | 553 |
| 29 June | 15037 | 560 |

## 6. Conclusions

The CERES-Rice version 3.0 model was evaluated to simulate crop growth, development and yield in the state of Kerala, India. Genetic coefficients were derived for the crop variety *Jaya* and utilised in the evaluation. It was envisaged that the model would provide insights for rice crop physiologists and agronomists about the response mechanisms to various weather/climate conditions. The model is found to be able to predict the phenological occurrence of the crop fairly well; this would enable farmers to take decisions on the crop management operations that can be directly linked to crop phenology.

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. As the CERES-Rice model is found to be capable of predicting the crop yield fairly well, it can serve as a tool in assessing yield potential of alternativee technologies and management practices from high-yielding places to low-yielding places. With the use of this model, the initial trial and error can be done using the computer, and only those varieties and management decisions that look promising would be transferred and tried in the field. The model developed is envisaged to help the agrotechnology transfer in the state of Kerala faster by reducing the time and cost otherwise involved.

Another finding of the study is that, even though the state receives good rainfall during the crop-growing season, the crops under rainfed conditions suffer from soil moisture stress because of the uneven distribution. Hence it is necessary to harness and store the excess water during the rainy period using appropriate methods in order to cater to its need during the non-rainy or lean periods.

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 framework 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, environment 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 double cropping.

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