CHAPTER 3

THE CERES-RICE MODEL

The CERES-Rice model developed along the lines of the CERES-Maize (Jones and Kiniry, 1986) and the CERES-Wheat models (Otter-Nacke et al., 1986). It was developed by Ritchie et al. (1986) and modified for transplanted rice by researchers at the International Fertilizer Development Center (IFDC) (Godwin and Singh, 1989). It is still undergoing testing and refining by scientists of the International Benchmark Site Network for Agrotechnology Transfer (IBSNAT) project. The model can simulate growth and development as well as grain yield of different rice varieties under a given agroclimatic condition. The nitrogen sub-model was recently incorporated into the model (Godwin and Singh, 1989). This nitrogen sub-model simulates the nitrogen cycle processes which include the outcomes of the organic matter turnover, mineralization and immobilization of nitrogen as well as the nitrification, denitrification and hydrolysis of urea. The model also simulates the effects of nitrogen stress on photosynthesis, leaf area development, tillering, senescence, and remobilization of plant nitrogen during grain filling (Jintrawet et al., 1990). Table 1 shows the general processes diagram of the CERES-Rice model.

Table 1. General processes diagram for CERES-Rice model

INPUT	PROCESS	OUTPUT
Controllable Inputs		
Variety seed	Plant growth	Grain yield
Plant spacing	Phasic development	Yield components
Date of sowing	Morphological development	Above ground biomass
Date & amount of irrigation	Soil water balance	Dates of phasic Developmental changes
Date & amount of N fertilization	Soil nitrogen balance	Optimal output at user selected frequency
Types of fertilizer N		Soil water balance components
Genetic coefficients		Root densities
Types of residues		Indices of nitrogen & nitrogen & water stress
Noncontrollable Inputs		
Daily weather data		
Day length		
soil properties & initial conditions		

Source: Ritchie, et al. (1986).

GENERAL FEATURES OF CERES-RICE MODEL

The following are the main features of the model:

- phasic development or duration of growth stages as influenced by genotype and environmental factors.
- biomass production and partitioning
- root systems dynamics
- effect of soil water deficit and nitrogen deficiency on the photosynthesis and photosynthate partitioning in the plant system.

The model assumes complete control of growth limiting factors such as weeds, insects, diseases and other management variables (i.e., phosphorus, potassium, liming, etc.) (Ritchie et al., 1986).

MODEL INPUTS

The CERES-Rice Model requires the following inputs.

(i) Daily weather data at least for the duration of the growing season. This includes solar radiation, maximum and minimum air temperatures and precipitation.

(ii) Soil initial conditions and properties which include drainage and runoff coefficients, evaporation and radiation reflection coefficients, rooting preference factors, soil water content, nitrogen and organic matter details at several depth increments, and information on the initial and saturated soil water content.

(iii) Management practices such as variety, plant density, sowing depth, planting depth, irrigation (date of application and amount), and nitrogen fertilization (date of application, type, and amount).

(iv) Latitude information of the production area. This information is required in order to calculate daylength during the cropping season.

(v) Genetic coefficients, the CERES-Rice models require variety-specific coefficients that account for genotypes differ in their response to environmental factors.

The definitions of the genetic coefficients of the rice crop are presented in Table 2. There are two types of genetic coefficients which are the developmental phenological or phasic coefficient designated as "P" coefficients and the growth coefficients which designated as "G". The P coefficients enable the model to predict events such as flowering and maturity. The P1 and P5 coefficients define the duration of the vegetative and grain filling stages, respectively. The P1 coefficient varies greatly among varieties. As the value of the P1 and P5 coefficients increase, the time required by a variety to reach maturity also increase.

Table 2. Phenology and growth genetic coefficients used in the CERES-Rice model version 2.10

Genetic coefficients	Definitions and unit
Phenology coefficients	
P1	Growing degree day (GDD) from seeding emergence to end of tillering stage with base temperature at 8°C.
P5	Growing degree day from flowering to end of main culm grain filling stage with base temperature at 8°C.
P20	Critical daylength for flowering (hours). This rages from 10 -13 hours.
P2R	Photoperiod sensitive coefficient (degree day delay hr^{-1}).
Growth coefficients	
G1	Potential spikelet (number per plant).
G2	Single grain weight (g).
G3	Tillering coefficient (ranges from 0.6-1.0 on a scale values).
G4	Temperature tolerance (Indica, Japonica, and Javanica).

Source : Singh, et al. (1988).

The growth coefficients represent the potential value for particular variety. Grain size is a genetic coefficient which varies with varieties. The genetic coefficient for grain size represents the grain size that can be achieved under ideal conditions. Grain yield is the product of grain size and grain number. Grain number depends upon the number of panicle which in turn depends on tiller numbers. Grain number, grain size, and tillering are determined by the genetic coefficient G1, G2, and G3, respectively.

GROWTH AND DEVELOPMENT

Phasic Development

The phasic development in the CERES-Rice model concerned with the duration of growth stages. The growth stages and their corresponding description are summarized in Table 3. The growth stages are numbered as 1 through 9. The active above ground growth stages are numbered 1 through 5. Stages 6 through 9 describe the other events in the crop cycle.

The model assumes that the developmental rates are directly proportional to temperature between 8° and 32°C. When the maximum and the minimum daily air temperatures are within this range, the thermal time is calculated as the average between the maximum and minimum air temperature of 8°C. That is,

daily thermal time (DTT) = [(max. temp. + min. temp.)/2] - 8

However, the thermal time requirements for each growth stage vary with variety.

Table 3. Phenological stages of the CERES-Rice model

Growth Stage	Event	Growing Plant parts
1	Juvenile stage	Roots, Leaves
2	Floral Induction	Roots, Leaves, Stems
3	End of leaf growth	Roots, Leaves, Stems, Panicles
4	Anthesis and Flowering	Roots, Stems, Panicles
5	Grain Filling	Grain
6	Physiological Maturity to Harvest	
7	Fallow or Presowing	
8	Sowing to Germination	
9	Germination to Emergence	

Source: Ritchie, et al. (1986).

Photosensitivity of a variety directly affects the thermal time requirement during the induction stage (Stage 2). A photoperiod sensitive variety has a longer thermal time requirement when the daylength is longer than the optimum photoperiod. The coefficient associated with the thermal time (P1, P2R, P20) have been calculated from phytotron studied on some varieties and from photoperiod studied (Vergara and Chang, 1976) for large a number of varieties. P1 is the approximate thermal time equivalent to basic vegetative phase; P2R can be calculated from the different photoperiod lengths; and P20, the optimum photoperiod when induction occurs, follows the same definition used by Vergara and Chang (1976).

BIOMASS PRODUCTION AND PARTITIONING

Germination

The germination factor used in the model was obtained from the 90 percent germination curve proposed by Livingston and Haasis (1983). Seed germination requires 45 degree days at base temperature of 8°C.

Leaf area and dry matter production

The total leaf area of a rice population is closely related to grain production because physiologically active leaves contribute to the photosynthesis of the plant (Ritchie et al., 1986). The photosynthetic rate is expressed as a function of the photosynthetically active radiation (PAR) as that the function of the model CERES-Maize (Jones and Kiniry, 1986) and CERES-Wheat (Ritchie and Otter, 1985). The percentage of incoming PAR intercepted by the canopy then becomes an exponential function of the leaf area index (LAI). The value of PAR above the canopy is assumed to be equal to 50 percent of the incoming solar radiation. The actual rate of dry matter production is usually less than the potential rate because of the environmental effects of non-optimum temperature, water stress, or nitrogen deficiency.

Dry matter partitioning

Partitioning of the assimilation of CERES-Rice model follows the general principle used in RICEMOD (McMennamy and O'Toole, 1983) where the assimilates are partitioned among the growing parts of each stage in proportional fractions. The partitioning of the assimilation when water stress and/or nitrogen deficiency occurs, however favor the roots than the top parts of plant.

ROOT SYSTEM DYNAMICS

Biomass is partitioned into shoots and roots. The proportion partitioned to the roots affects root density and consequently the ability of the root system to supply water and nutrients to the shoot. The fraction of assimilates partitioned to the roots depends primarily on the growth stages of the crop which declines as the plant matures. However, at all growth stages except stage 5 the fraction partitioned to the roots increase with water deficits and/or nitrogen deficiency.

The total root growth in a day is determined by the amount of biomass partitioned to the roots. Distribution of roots in the soil is determined by rooting preference factor that decreases with depth is input for each soil layer. The preference factor of a layer is reduced when the soil water content is below a threshold value. Thus, root growth in that layer decreases when a particular soil layer becomes quite dry. In contrast, while compensatory root growth occurs elsewhere in the profile where the water is favorable.

The potential rate of downward root growth is assumed to be proportional to the rate of plant development which is influence by temperature. Water content of each depth is used to determine the distribution of root growth in the profile. Estimation of root length density is useful in order to understand the mass of assimilate partitioned to the roots. It is done by assuming a constant proportionality between root mass and length. There is a small reduction in root length in each depth to account for root sloughing.

GRAIN YIELD

According to Yoshida (1981) the 1,000-grain weight of rice crop is stable varietal characteristic. Individual grain weight varies to some extent but the mean value is constant. In the CERES-Rice model, grain weight is the product of the grain growth rate and the duration of grain filling. A genetic coefficient (G2) determines the grain growth rate at optimum conditions. Grain growth rate varies among varieties according to three main grain size classifications i.e., long, medium, and short.

In this model, grain yield is directly proportional to the panicle weight. The model does not set any maximum yield potential. Rate and duration of panicle growth, as influenced by the environment and plant size, control yield.

SOIL WATER BALANCE

The soil water balance is calculated in order to evaluate the possible yield reduction caused by soil and plant water deficits. However, if the soil water balance is assumed non-limiting then it can be by passed. This part of the model includes user-selected soil depth increments where water balance calculations are made.

Water contents in any layer of the soil can be increased due to infiltration of rain, irrigation water, or flow from an adjacent layer. On the other hand water content can decrease if there is soil evaporation, root absorption, or flow to the adjacent layer. The limits to which water content increases or decreases are also input for each layer at the lower limit of plant water availability, the field drained upper limit, and the field saturated water content.

Infiltration is calculated as the difference between daily precipitation and runoff. It is estimated using a Soil Conservation Service Curve Number technique as modified for layered soil by Williams et al. (1984). When irrigation inputs are encountered in the model the runoff estimation is by passed, thus allowing all irrigation to infiltrate.

Drainage is calculated as a function of the water content above the drained upper limit (DUL). Evapotranspiration (ET) is calculated by using the procedures presented by Ritchie (1972). Potential ET is calculated by using an equilibrium evaporation concept as modified by Priestly and Taylor (1972).

Root water uptake is calculated by using an empirical evaluation of the maximum possible single root water uptake rates. The maximum possible uptake per unit root length in each soil layer from the estimate of root length density and soil water is converted to the maximum uptake for the entire root system. If this maximum uptake value exceeds the calculated potential transpiration then transpiration is assumed to occur at potential rate. If the maximum uptake for the entire root zone is less than potential transpiration then the actual uptake becomes the maximum uptake and the transpiration is reduced at that value. This reduction in transpiration expressed as a fraction of the potential is used to reduce photosynthesis, leaf expansion, and assimilate partitioning in the growth subroutine.

NITROGEN COMPONENT

The nitrogen subroutine the CERES-Rice model can be by passed when nitrogen fertilization is considered non-limiting. Included in the nitrogen subroutine is the initiation of soil N condition and fertilizer management, as well as transformation process of humus, organic nitrogen, soil nitrate, and soil ammonium into N forms usable by the plant system. The process involves the mineralization of organic nitrogen and the immobilization of mineral nitrogen from organic decomposition based on the mineralization immobilization and routines in the PAPRAN program (Seligman and van Keulen, 1981). Nitrification of ammonium in each soil layer and denitrification occurred whenever the soil in the layer is greater than the drained upper limit and the NO_3-N concentration is greater than 1.0 g N/mg soil. This component of the model calculates the demand for N by the crop, the supply of N available to the crop, and the N uptake by the crop. Nitrogen stress develops when actual nitrogen concentration of the stover (non-grain shoot) is less than the critical N requirement and that stress is severe when the actual concentration is equal to the minimum allowable value. Nitrogen stress affects leaf expansion, photosynthesis, and grain N concentration in the growth subroutine.