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# Calibration and Evaluation of CERES Rice Model under Different Nitrogen- and Water-Management Options in Semi-Mediterranean Climate Condition

E. AMIRI,[1] M. REZAEI,[2] M. BANNAYAN,[3] AND S. SOUFIZADEH[4]

[1]Department of Agriculture, Lahijan Branch, Islamic Azad University, Lahijan, Iran
[2]Rice Research Institute of Iran, Rasht, Iran
[3]Ferdowsi University of Mashhad, Faculty of Agriculture, Mashhad, Iran
[4]Department of Agroecology, Environmental Sciences Research Institute, Shahid Beheshti University, Tehran, Iran

*The objective of this study was the evaluation of the CERES rice model under different nitrogen- and water-management conditions in northern Iran. A 3-year field experiment was conducted at the experimental farm of the Iranian Rice Research Institute in Rasht, Iran, from 2005 to 2007. The experiment was established in a split-plot design with three irrigation regimes (continuous submergence, irrigation at 5-day intervals, and irrigation at 8-day intervals) as the main plot, four nitrogen levels (0, 45, 60, and 75 kg N ha$^{-1}$) as the subplot, and three replications. Evaluation simulated and measured grain yield, total crop biomass, N content of grain, and crop biomass by adjusted coefficient of correlation and by absolute and normalized root mean square errors (RMSE). Results showed that predicted grain yields agreed well with observed yields ($RMSE_a = 297$ and $RMSE_n = 8\%$). Simulated and observed total dry-matter yields were also in reasonable agreement ($RMSE_n = 862$ and $RMSE_n = 10\%$). Observed and predicted N uptake by rice showed good agreement. The CERES rice model can be applied to research purposes (irrigation and nitrogen) under northern Iranian conditions.*

**Keywords** CERES rice, irrigation, model, nitrogen, rice

## Introduction

The need for increasing agricultural productivity on a sustainable basis is the primary concern for the agricultural research and development community (Singh et al. 2002). Anzoua et al. (2010) stated that global rice production needs to grow at a rate of ca. 1.6% year$^{-1}$ for the period 1990–2030 to meet the projected demand by the continuously increasing world population. Such an increase in rice grain supply must come from productivity growth in existing cultivated area rather than expanding the cultivation area to marginal lands with attendant deforestation and soil degradation (Sheehy et al. 1998; Evans and Fischer 1999).

Received 9 September 2011; accepted 4 March 2012.
Address correspondence to E. Amiri, Department of Agriculture, Lahijan Branch, Islamic Azad University, Lahijan, Iran. E-mail: eamiri57@yahoo.com

At present, rice yield is mostly limited by water and nitrogen (N) availability. Nitrogen is generally the most limiting nutrient in high-yielding rice systems, and adequate N supply is required throughout the active growing period (Singh, Tripathy, and Chopra 1999). According to Barker and Dawe (2001) and Pingali, Hossain, and Gerpacio (1997) current yields of irrigated rice are associated with large applications of fertilizer N. Cassman et al. (1998) and Peng et al. (2006) stated that although N supply drives productivity, low fertilizer N-use efficiency is a major characteristic of irrigated rice systems. A well-managed rice crop should have an agronomic N-use efficiency of 15–25 kg $kg^{-1}$ under irrigated conditions if the N input is optimal (Dobermann and Fairhurst 2000). According to Zheng et al. (2007), farmers often apply more N fertilizer than the required amount, thus increasing the risk of environmental pollution. Lin et al. (2009) found that standard rice-management practices increase the need for fertilizer and raise the fertilizer input without commensurate returns. The improper timing of N application also contributes to the poor fertilizer N-use efficiency for rice production (Huang et al. 2008).

Water scarcity for agricultural production has been on the rise and development of new water resources is increasingly costly. So, increased efficiency in the use of water is essential for improving rice production (Tuong and Bhuiyan 1999). Many researchers have suggested water-saving irrigation techniques as one promising strategy to help increase rice water productivity at the farm level (Tuong and Bhuiyan 1999; Belder et al. 2005). The high water demand of irrigated rice mainly arises from the need to keep a permanent layer of water on the field (Guerra et al. 1998). The permanent water layer causes evaporation, seepage, and percolation to be greater than in nonflooded fields. Numerous studies have demonstrated that reducing the water depth and maintaining the soil at saturated and alternate wet and dry conditions could save 30–75% of irrigation water without substantially lowering yield compared with continuous flooding (Sandhu et al. 1980; Mishra, Rathore, and Pant 1990).

Current N fertilizer recommendations for rice in Asia have generally been established under continuously submerged conditions (Belder et al. 2005). Results of different research show that the N dynamic could be affected in different ways under submerged/nonsubmerged conditions (Eriksen, Kjeldby, and Nilsen 1985; Fillery and Vlek 1982). George et al. (1992) also stated that a change from a flooded to a nonflooded (either short or long) soil in rice culture brings about a transition in soil aeration status from anaerobic to aerobic. The duration of the flooded (or nonflooded) period and the transition from aerobic to anaerobic status has a major impact on accumulation and dissipation of soil mineral N. Bouman et al. (2001) and Lin et al. (2004) reported that under standard rice management, continuous flooding constrains plant performance and N utilization instead of optimizing N application rate with less water.

Guerra et al. (1998) stated that most of the results on the N dynamic in rice under different water-management conditions were obtained in pot experiments, and the interaction between water and N has been little studied under field conditions. Thus, with the development of water-saving practices, there is a need to re-evaluate the N economy of rice fields.

Crop-growth simulation models can assist agronomy by integrating physiological understanding, agronomic practices, and the environment (Messina et al. 2006; Bannayan et al. 2007). These models could effectively be used to improve yield in crops through optimizing different combinations of management practices for target environments (Shorter, Lawn, and Hammer 1991; Cooper and Hammer 1996). Following this line of thought, crop growth simulation models in combination with field experiments are powerful tools to explore the N utilization of rice fields under water-saving regimes (Arora 2006; Chahal et al. 2007; Jing et al. 2007). This is especially the case in developing countries where detailed and long-term field experiments are often difficult to conduct because of financial and personnel limitations and the ability to extrapolate the results to other environments is of great importance. These models synthesize current insights in physiological and ecological crop growth processes and can help increase insight in relationships among fertilizer rates, water-saving regimes, and crop performance.

The objective of the present study was to calibrate and evaluate the CERES rice model under varying N levels and water regimes.

## Materials and Methods

### *Experimental Design, Crop Establishment, and Crop Management*

A 3-year field experiment was conducted at the experimental farm of the Iranian Rice Research Institute in Rasht (37′ 12° N; 49′ 38° S; 7 m below sea level) from 2005 to 2007. The soil was sandy loam. At the start of the experiment, soil physical (texture, bulk density, hydraulic conductivity, drained upper limit, drained lower limit, field capacity) and chemical [pH, cation exchange capacity (CEC), organic carbon (OC), total N, phosphorus (P), potassium (K)] properties of the field were determined up to a depth of 40 cm, at an interval of 10 cm, following standard procedures (Table 1). The site has a warm semi-Mediterranean climate with warm summers, mild winters, annual means of 1441 mm rainfall, and 16.8 °C temperature. Daily weather data of maximum and minimum temperatures, maximum and minimum relative humidity, rainfall, and sunshine hours were collected for the entire growing seasons from a meteorological station beside the Iranian Rice Research Institute (Figures 1 and 2; data on relative humidity and sunshine hours not shown).

**Table 1**
Soil physical and chemical characteristics of the experimental site before sowing the rice crop

| | Depth (cm) | | | |
|---|---|---|---|---|
| Soil characteristics | 0–10 | 10–20 | 20–30 | 30–40 |
| Texture | | | | |
| Sand (%) | 14 | 17 | 9 | 11 |
| Silt (%) | 39 | 39 | 44 | 42 |
| Clay (%) | 47 | 44 | 47 | 47 |
| Bulk density (g cm$^{-3}$) | 1.1 | 1.2 | 1.32 | 1.31 |
| Water content at saturation | 0.65 | 0.62 | 0.62 | 0.60 |
| Water content at FC (0.01 MPa) | 0.40 | 0.40 | 0.41 | 0.42 |
| Water content at PWP (1.5 MPa) | 0.27 | 0.30 | 0.30 | 0.30 |
| $K_{SAT}$ (cm day$^{-1}$) | 57.54 | 30.8 | 0.40 | 11.8 |
| pH | 7.15 | 7.23 | 7.26 | 7.08 |
| CEC (meq 100g$^{-1}$) | 33 | 32 | 31 | 31 |
| Organic carbon (%) | 1.72 | 1.54 | 1.25 | 0.76 |
| Total N (%) | 0.16 | 0.14 | 0.074 | 0.047 |
| Extractable P (ppm) | 10.1 | 7.3 | 5.2 | 3.2 |
| Extractable K (ppm) | 195 | 176 | 185 | 161 |

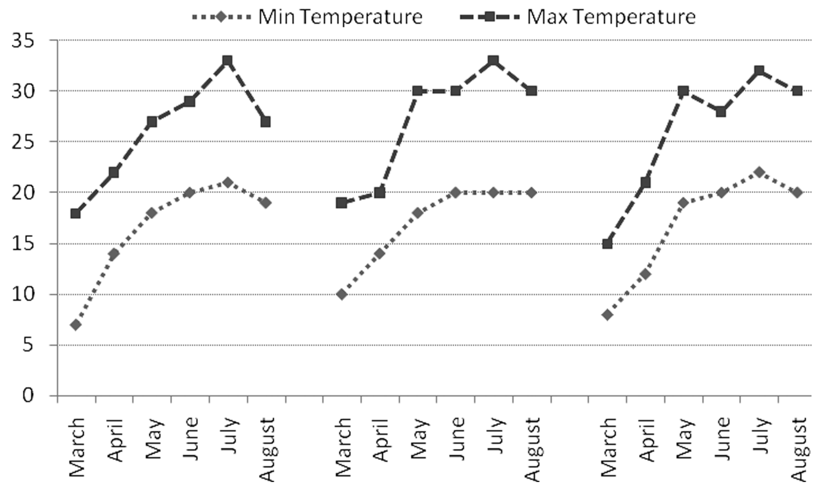


**Figure 1.** Monthly minimum and maximum air temperatures (°C) during the growing periods of rice in 2005, 2006, and 2007 growing seasons (left to right, respectively).

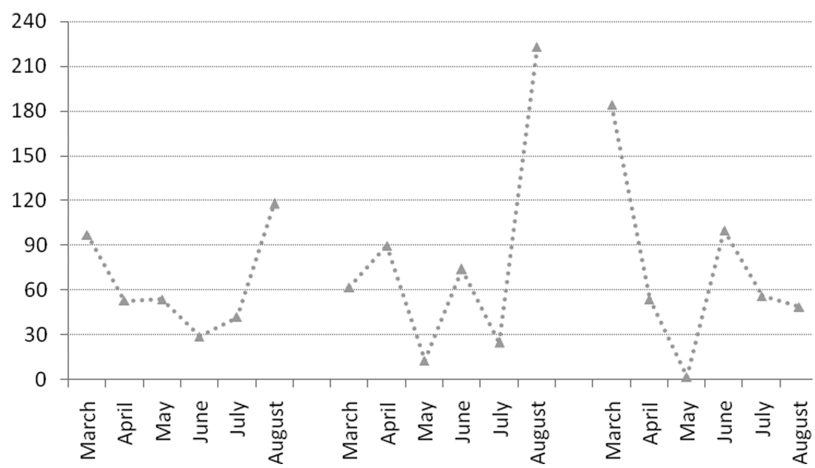


**Figure 2.** Monthly rainfall during the growing periods of rice in 2005, 2006, and 2007 growing seasons (left to right, respectively).

The experiment was established in a split-plot design with three irrigation regimes as the main plot, four N levels as the subplot, and three replications. The plot size for the subplots was 15 $m^2$ (5 m × 3 m). The irrigation regimes were continuous submergence, irrigation at 5-day intervals, and irrigation at 8-day interval. The four N rates applied were 0, 45, 60, and 75 kg N $ha^{-1}$. At 45 kg N $ha^{-1}$, all N was applied at transplanting while 60 and 75 kg N $ha^{-1}$ treatments were applied in splits of 50% at transplanting and 50% at maximum tillering. Cultivar Hashemi was used in the experiment, a variety widely grown by farmers in northern Iran. Land preparation consisted of wet tillage followed by harrowing, a process referred to as "puddling." Puddling is practiced to create a semi-impermeable layer (hardpan) and to ease transplanting. The plots were hydrologically separated by plastic sheets installed to 30 cm below the soil surface to restrict water and N flows between adjacent plots.

Phosphorus (P) and potassium (K) were applied at transplanting in all plots at 25 kg phosphorus pentoxide ($P_2O_5$) as triple superphosphate and 75 kg potassium oxide ($K_2O$) of potash (KCL) $ha^{-1}$. Thirty-day-old seedlings were transplanted on 10 May 2005, 15 May 2006, and 20 May 2007. Weeds, insects, and diseases were effectively controlled to avoid yield loss. All treatments were harvested on 11–15 August. The amount of irrigation water applied to each plot at each irrigation from transplanting until maturity was measured using a pipe system equipped with flow meters that were installed in the field.

Dates of heading and physiological maturity were determined for each treatment. Heading and physiological maturity occurred when 50% or more of the selected plants (tagged after transplanting) reached the specified stage. All samples were then oven dried at 70 °C for 48 h and weighed. In all 3 years of experiment, grain yield and aboveground biomass (after drying at 70 °C for 48 h) were determined from a 5-$m^2$ area at maturity. The N contents of grain and of the whole crop were determined using the Kjeldahl method (Bremner 1960).

### *CERES Rice Description*

The summary description presented here about the DSSAT-CSM is directly copied from the review article by Jones et al. (2003) in which they explained the DSSAT crop model in detail. The DSSAT-CSM simulates growth, development, and yield of a crop growing on a uniform area of land under prescribed or simulated management as well as the changes in soil water, carbon (C), and N that take place under the cropping system over time. The model is structured using the modular approach described by Jones, Keating, and Porter (2001) and Porter, Jones, and Braga (2000). The DSSAT has a main driver program, a land unit module, and modules for the primary components that make up a land unit in a cropping system. The primary modules are for weather, soil, plant, soil–plant–atmosphere interface, and management components. Collectively, these components describe the time changes in the soil and plants that occur on a single land unit in response to weather and management. The main function of the weather module is to read or generate daily weather data. It reads in daily weather values (maximum and minimum air temperatures, solar radiation and precipitation, relative humidity, and wind speed when available) from the daily weather file. The soil in the land unit is represented as a one-dimensional profile; it is homogenous horizontally and consists of a number of vertical soil layers. The soil module integrates information from four submodules: soil water, soil temperature, soil C and N, and soil dynamics. The soil–plant–atmosphere module computes daily soil evaporation and plant transpiration. This module brings together soil, plant, and atmosphere inputs and computes light interception by the canopy, potential evapotranspiration, and actual soil evaporation and plant transpiration. It also computes the root water uptake of each soil layer. The daily weather values as well as all soil properties and current soil water content, by layer, are required as input. In addition, leaf area index (LAI) and root length density for each layer are needed.

The species file contains information on base temperatures and optimum temperatures for developmental processes and growth processes. The file also includes information on photosynthesis, $N_2$ fixation, tissue composition, growth, and maintenance respiration coefficients. Cultivar differences are created by 15 cultivar traits. The cultivar traits include two daylength sensitivity traits, five important life-cycle phase durations, light-saturated leaf photosynthesis, vegetative traits, and reproductive traits. Phenology is simulated by using information from the species file, which contains cardinal temperature values, as well as information from the cultivar and ecotype files, which contain physiological day durations for respective life-cycle phases. Life-cycle progress through any given phase depends on a physiological day accumulator as a function of temperature and day length, in many cases. When the physiological day accumulator reaches a value defined by a threshold given in the cultivar file, a new growth stage is triggered. Crop photosynthesis can be calculated by two options: (1) daily canopy photosynthesis, similar to radiation-use efficiency models, or (2) hourly hedgerow light interception and leaf-level photosynthesis. The daily canopy photosynthesis option predicts daily gross photosynthesis as a function of daily irradiance for a full canopy, which is then multiplied by factors 0–1 for light interception, temperature, leaf N status, and water deficit. The hourly hedgerow photosynthesis light interception approach is described by Boote and Pickering (1994). On an hourly time step during each day, interception and absorption of direct and diffuse light components are computed based upon canopy height and width, leaf area index (LAI), leaf angle, row direction, latitude, day of year, and time of day (Boote and Pickering 1994). Photosynthesis of sunlit and shaded leaves is computed hourly using the asymptotic exponential response equation, where quantum efficiency and light-saturated photosynthesis rate variables are dependent on $CO_2$ and temperature (Boote and Pickering 1994). Hourly canopy photosynthesis on a land-area basis is computed from the sum of sunlit and shaded leaf contributions by multiplying sunlit and shaded leaf photosynthetic rates by their respective LAIs. Gross photosynthesis is integrated hourly to provide a daily total value.

Growth of new tissues depends on daily available carbohydrate, partitioning to different tissues, and respiration costs of tissue synthesis. During vegetative growth, the model follows a partitioning pattern dependent on vegetative growth stage but modified by water deficit and N deficiency. Beginning at flowering, cohorts of flowers, pods, and seeds are added daily. Reproductive tissues have first priority for assimilation over vegetative tissues, up to a maximum reproductive partitioning factor. This factor may be less than 1.0 for indeterminate plants (such as peanut and tomato) and 1.0 for determinate plants, indicating that reproductive tissue eventually can utilize 100% of the assimilate. During seed fill, N is mobilized from vegetative tissues. As a result photosynthesis declines and leaf abscission increases. Growth respiration and conversion efficiency follow the approach of Penning de Vries and van Laar (1982), where the glucose cost for respiration and for condensation are computed as a function of the composition of each tissue. Maintenance respiration depends on temperature as well as gross photosynthesis and total crop mass minus protein and oil in the seed. Maintenance respiration is subtracted from gross daily photosynthesis to give available carbohydrates for new tissue growth.

The management module determines when field operations are performed by calling submodules. Currently, these operations are planting, harvesting, applying inorganic fertilizer, irrigating and applying crop residue and organic material.

### *Model Inputs*

The DSSAT models require the minimum data set for model operation. They encompass data on the site where the model is to be operated, on the daily weather during the growing cycle, on the characteristics of the soil at the start of the growing cycle or crop sequence, and on the management of the crop (e.g., seeding rate, fertilizer applications, and irrigations). Required weather data includes daily records of total solar radiation incident on the top of the crop canopy, maximum and minimum air temperature above the crop, and rainfall. Soil inputs include the classification of the soil, the water-holding characteristics of different soil layers plus their bulk density, organic C, pH, drainage coefficient, and root growth factor. Initial values of soil water, nitrate, and ammonium are needed as well as an estimate of the above- and belowground residues from the previous crop.

All aspects of crop management, including modifications to the environment (e.g., photoperiod extension) as imposed in some crop physiology studies, are needed. Typical crop-management factors include planting date, planting depth, row spacing and direction, plant population, fertilization, irrigation, inoculation, residue applications, tillage, and harvest date. The DSSAT-CSM also requires coefficients for the genotypes involved (Hunt 1993; Ritchie 1993).

### Model Calibration

The calibration of the CERES rice model was based on data from end-of-season samplings of grain yield, crop biomass, and N contents in biomass and in grain in 2007 field experiment. Growth and development of crop varieties differing in maturity in CERES models are distinguished using the genetic coefficients. The genetic coefficients of the rice cv. Hashemi that affect the occurrence of phonological stages in the CERES models were derived using the GENCALC software of DSSAT v 4.2. This program estimates the coefficients for a genotype by iteratively running the crop model with an approximate value of the coefficients concerned. It compares the simulated and measured values and then automatically alters the cultivar coefficients until the simulated and measured values match or are within predefined error limits. Crop measurements required for this operation are the date of the key phenological stages, including anthesis and physiological maturity, and yield and yield components (Hunt et al. 1993).

### Model Evaluation

The performance of the CERES rice model was evaluated using data sets of 2005 and 2006 field experiments. Given that none of the model parameters were calibrated on the basis of these 2 years of experiments, the model performance evaluation can be considered as a true validation (Akponikpe et al. 2010). According to Bouman and van Laar (2006), no single measure can indicate how well a simulation model performs, so a combination of graphical and statistical measures (Bouman and van Laar 2006; Timsina et al. 2008; Feng et al. 2007) were used. We graphically compared the simulated and measured grain yield, biomass at harvest, N content of biomass at harvest, and N content of grain. The statistical measures used were divided into two groups: summary measures, which describe the quality of simulation, and difference measures, which try to quantify errors (Singh, Tripathy, and Chopra 2008). Summary measures used in the present study were the mean of measured and simulated values, the standard deviations (SD) of the observations and simulations, the slope $\alpha$, intercept $\beta$, and coefficient of determination ($R^2$) of the linear regression line between simulated and measured values. The different measures were based on the analysis of residual errors, that is, the difference between simulated and measured values. We computed the absolute and normalized root mean square errors ($RMSE_a$ and $RMSE_n$, respectively). The measures were calculated as follows:

$$RMSE_a = \left[ N^{-1} \sum_{i=1}^{n} (S_i - O_i)^2 \right]^{0.5} \tag{1}$$

$$RMSE_n = \left( \frac{RMSE_a}{mean\ of\ all\ measured\ values} \right) \times 100 \tag{2}$$

where $S_i$ and $O_i$ are simulated and measured values, respectively. One would expect to have, for good model performance, values of RMSE as close as possible to 0. A model produces experimental data perfectly when $\alpha$ is close to 1, β is close to 0, $R^2$ is close to 1, $RMSE_a$ is similar to the SD of measured values, and $RMSE_n$ is similar to the coefficient of variation (CV) of measured values.

## Results and Discussion

### *Model Calibration*

The calibrated genetic coefficients (cv. Hashemi) as derived by GENCALC for CERES rice are given in Table 2. Table 3 shows the goodness-of-fit parameters for grain yield and aboveground biomass at harvest of the whole data set. The model simulated aboveground biomass quite well, with the absolute and normalized RMSE values two times greater than the error in the measured value (Table 3). For aboveground biomass, the slope was far from 1, and the intercept β was high, indicating general overestimation of simulated values. The relatively low $R^2$ reflects the large spread of the data. Almost the same pattern was observed for grain yield. The model simulated grain yield generally good. The slope in this trait was a little bit greater than that of aboveground biomass while the intercept β

**Table 2**
Genetic coefficients of the rice cv. Hashemi as derived by GENCALC of DSSAT model

| Genetic parameters | Description | Coefficient for Hashemi |
|---|---|---|
| P1 | Time period (expressed as growing degree days (GDD) in °C above a base temperature of 9 °C from seedling emergence during which the rice plant is not responsive to changes in photoperiod. | 300.0 |
| P20 | Critical photoperiod or the longest day length (in h) at which the development occurs at a maximum rate. | 5.0 |
| P2R | Extent to which phasic development leading to panicle initiation is delayed (expressed as GDD in °C) for each hour increase in photoperiod above P20. | 13.5 |
| 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. | 350.0 |
| 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. | 55.0 |
| G2 | Single grain weight (g) under ideal growing conditions, i.e., nonlimiting light, water, and nutrients and absence of pests and diseases. | 0.0250 |
| G3 | Tillering coefficient (scaler value) relative to IR64 cultivar under ideal conditions. | 1.00 |
| G4 | Temperature tolerance coefficient. Usually 1.0 for varieties grown in normal environments. | 1.00 |

**Table 3**
Evaluation results for CERES rice simulations of final aboveground biomass and yield, for the calibration and validation conditions

| Year | Crop variables | N | $X_{obs}$ | $X_{sim}$ | $\alpha$ | β | $R^2$ | $RMSE_a$ (kg N ha$^{-1}$) | $RMSE_n$ (%) |
|---|---|---|---|---|---|---|---|---|---|
| | Calibration | | | | | | | | |
| 2007 | Final biomass (kg ha$^{-1}$) | 12 | 8880 | 8996 | 0.41 | 5331 | 0.65 | 951 | 11 |
| | Yield (kg ha$^{-1}$) | 12 | 3493 | 3733 | 0.47 | 2079 | 0.82 | 428 | 12 |
| | Validation | | | | | | | | |
| 2006 | Final biomass (kg ha$^{-1}$) | 12 | 9255 | 9565 | 2.11 | −9984 | 0.91 | 1011 | 10 |
| | Yield (kg ha$^{-1}$) | 12 | 3842 | 3888 | 0.70 | 1158 | 0.86 | 232 | 6 |
| 2005 | Final biomass (kg ha$^{-1}$) | 12 | 8052 | 8081 | 0.50 | 3881 | 0.78 | 548 | 7 |
| | Yield (kg ha$^{-1}$) | 12 | 3248 | 3260 | 0.70 | 983 | 0.75 | 167 | 5 |

**Table 4**
Evaluation results for CERES rice simulations of N content in aboveground biomass and grain, for the calibration and validation conditions

| Year | Crop variable | N | $X_{obs}$ | $X_{sim}$ | $\alpha$ | β | $R^2$ | $RMSE_a$ (kg N ha$^{-1}$) | $RMSE_n$ (%) |
|---|---|---|---|---|---|---|---|---|---|
| | Calibration | | | | | | | | |
| 2007 | Amount of final N in crop (kg ha$^{-1}$) | 12 | 71 | 63 | 1.19 | −20.9 | 0.78 | 8.7 | 12 |
| | Amount of final N in grain (kg ha$^{-1}$) | 12 | 37 | 39 | 1.16 | −4.1 | 0.47 | 4.7 | 12 |
| | Validation | | | | | | | | |
| 2006 | Amount of final N in crop (kg ha$^{-1}$) | 12 | 76 | 73 | 0.49 | 34.8 | 0.66 | 9.4 | 12 |
| | Amount of final N in grain (kg ha$^{-1}$) | 12 | 51 | 41 | 0.67 | 6.6 | 0.88 | 10.6 | 20 |
| 2005 | Amount of final N in crop (kg ha$^{-1}$) | 12 | 56 | 61 | 0.67 | 24.1 | 0.73 | 7.2 | 12 |
| | Amount of final N in grain (kg ha$^{-1}$) | 12 | 42 | 33 | 0.53 | 10.1 | 0.76 | 10.1 | 23 |

was more than that half that of aboveground biomass. The relatively high $R^2$ reflects the low spread of the data.

The simulated and observed N content of total crop biomass and of grain at harvest are presented in Table 4. The model provided very satisfactory estimate for the N content of grain. Almost all goodness-of-fit parameters indicated a close association between simulated and measured N content of grain. The model provided almost satisfactory estimate for the N content of total crop biomass. However, in the case of N content of grain, low $R^2$ reflected the large spread of the data.

### *Model Evaluation*

*Grain Yield and Total Crop Biomass.* The graphical comparison between simulated and measured grain yield is presented in Figure 3. The CERES rice model simulated grain yield in 2005 quite well. As observed, N application could considerably increase simulated grain yield compared to no-N application treatment. However, by increasing the N application rate beyond 45 kg $ha^{-1}$, the rice response not only did not increase but also decreased. It is also noticeable that the model could simulate rice response to N better under continuous submergence than under the other two irrigation regimes. The performance of the model was weaker in 2006 and 2007 compared to that in 2005. In 2006, rice responded differently to N application; that is, the simulated response to greater N rates was observed up to 60 kg applied N, but beyond that little increase or even a decrease occurred in rice grain yield. It could also be observed that the model simulated grain yield better under 8-day irrigation intervals than under the other two irrigation regimes. The simulation pattern of grain yield in 2007 was similar to that in 2006. The main difference, however, was that the model overestimated rice grain yield under the two lowest N application rates in this year. The model could satisfactorily simulate rice grain yield at 60 kg applied N under all irrigation regimes.

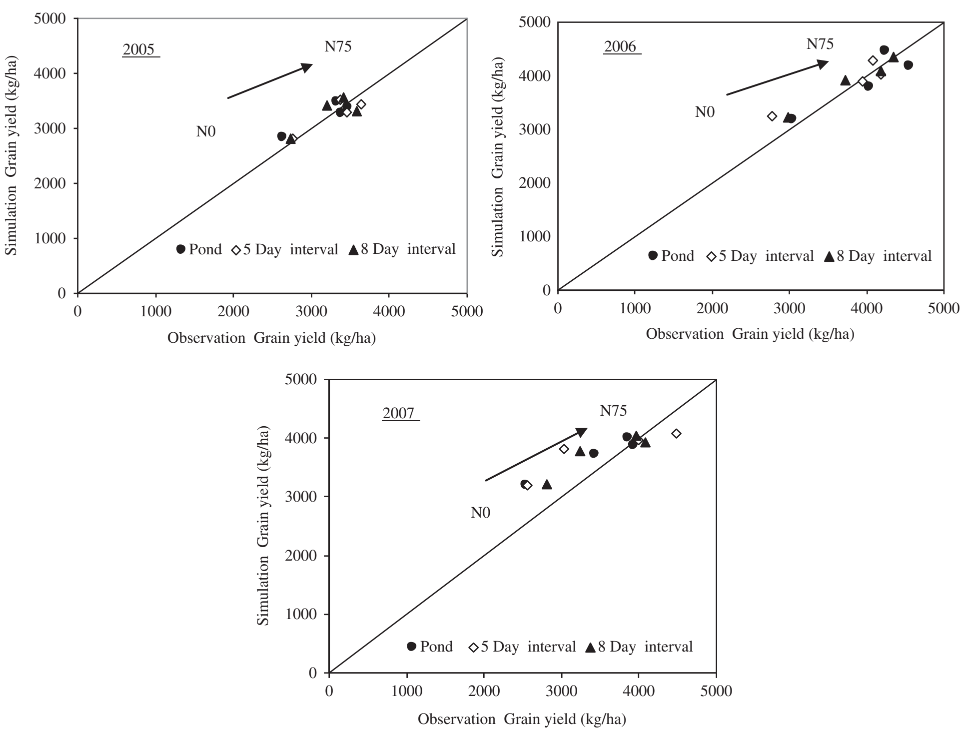


**Figure 3.** Evaluation of CERES rice model for grain yield under different N rates and water-saving regimes.

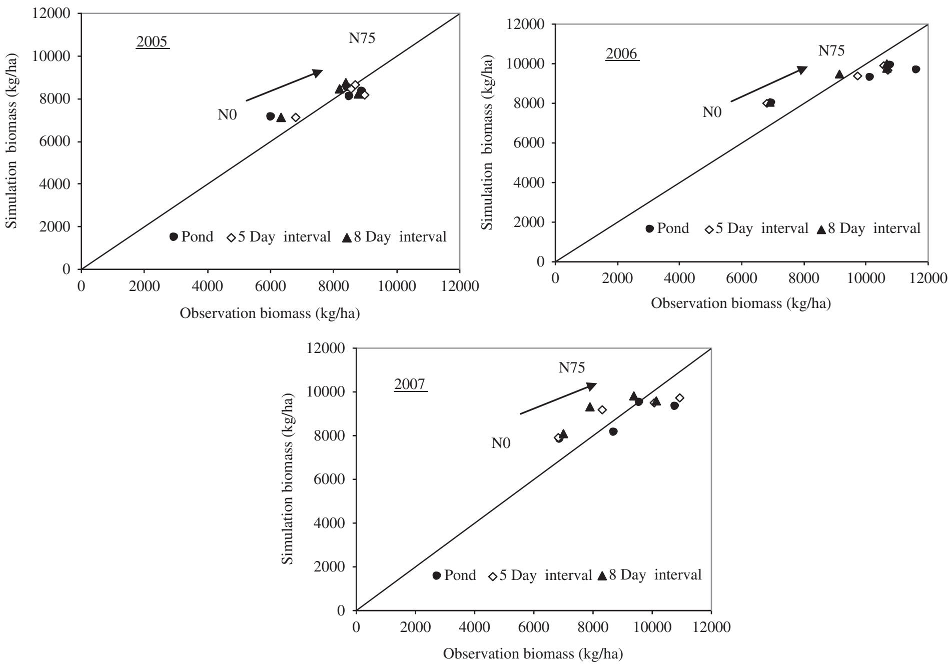


**Figure 4.** Evaluation of CERES rice model for final aboveground biomass under different N rates and water-saving regimes.

The graphical performance of the CERES rice model in simulating total crop biomass at harvest is presented in Figure 4. Similar to the simulation results of the grain yield, the best performance of the model in simulating total crop biomass was obtained in 2005. The greatest increase in crop biomass in response to N was observed up to 45 kg applied N; beyond that little increase was obtained. Application of 75 kg N ha$^{-1}$ decreased crop biomass at harvest under the two water-saving regimes. The CERES rice model could not simulate crop biomass satisfactorily in 2006. As observed in Figure 4, the model underestimated the biomass in each irrigation regime for all N rates except for N0, in which the values were overestimated. The greatest crop biomass in all irrigation regimes was achieved where 60 kg N ha$^{-1}$ was applied. This was similar to the response of simulated grain yield in this year. In 2007, although the spread in the simulated crop biomass data was larger than that in 2006, the data were more evenly distributed around the 1:1 line. The simulated crop biomass at 60 kg applied N under all irrigation regimes was closer to the 1:1 line while the values of crop biomass at the two lowest N application rates were overestimated. The model also underestimated crop biomass at the greatest N application rate regardless of the irrigation regime. On the other hand, in 2007 a bigger shift occurred in the simulated crop biomass from 45 kg applied N to 60 kg applied N under continuous submergence compared to the other two irrigation regimes.

Figure 5 compares simulated with measured total final biomass (Figure 5A) and yield (Figure 5B) across all calibration and validation data. For reference, the 1:1 line is shown. The RMSE was 297 kg ha$^{-1}$ and normalized RMSE was 8% for measured yields. Crop biomass was with a RMSE of 862 kg ha$^{-1}$ and normalized RMSE 10% for measured total biomass.

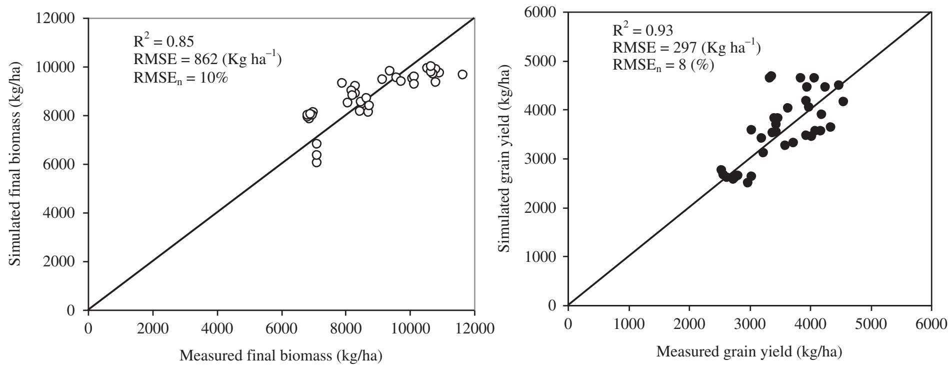


**Figure 5.** Simulated versus measured final aboveground biomass (A) and grain yield (B) from data set 2005–2007.

Timsina and Humphreys (2006) reported that CERES rice model predicted grain and biomass yield fairly well (normalized RMSE = 4–5%) from published studies across Asia and Australia, but model performance was poorer under conditions of low N, water deficit, and low temperatures during the reproductive stages. Matthews et al. (2000) reported fairly good prediction of grain and aboveground biomass yield (RMSE = 1.1 and 3.9 ton/ha, respectively) at Los Baños, Philippines, and Hangzhou, China, except for three treatments with midseason drainage in the dry season at Los Baños.

In northern Bangladesh, simulated yields of BR14 and BR11 genotypes were either over- or underestimated (RMSE = 1.2 t/ha), with large underpredictions for 0 N (Timsina et al. 1998). Mahmood et al. (2004) reported satisfactory performance of the model, with observed yields from 2.9 to 6.7 t ha$^{-1}$ and simulated from 2.6 to 7.3 t ha$^{-1}$, and RMSE of 1.3 t ha$^{-1}$, for 16 locations representing major rice-growing regions of central and northern Bangladesh.

Pathak et al. (2004) evaluated the CERES rice model using data from a range of water regimes (saturated to frequent intermittent wetting and drying to prolonged midseason drying) and N (0 to recommended to supraoptimal dose) management treatments for three growing environments in northwestern India. There was good agreement for grain yield (RMSE = 0.72 ton ha$^{-1}$) and reasonable agreement for dry-matter yield (RMSE = 2.6 t ha$^{-1}$) in well-fertilized (N) treatments, but generally poor agreement for the 0 N treatments. In northwestern India, RMSE for grain yield was 1.7 t/ha, indicating a large discrepancy between simulated and observed data (Timsina et al. 1995). Rao, Sebastian, and Subash (2002) in Kerala, India, reported good yield prediction (RMSE = 0.2 t ha$^{-1}$) in 1 year.

In Australia, simulated grain and total biomass yields were within 10% and 3%, respectively, of the observed yields in 1 year, but across several years and sites, there were large discrepancies, especially in cold years, due to the model's inability to simulate sterility induced by cold damage (Godwin, Meyer, and Singh 1994; Meyer et al. 1994). Amien et al. (1996) reported that the CERES rice model underpredicted grain yield by 10–20% in Indonesia. In different locations in Thailand, the model predicted grain and biomass yields quite well (Tongyai 1994).

*Nitrogen Content of Crop Biomass and Grain.* The results of graphical evaluation of the CERES rice model for simulating the N content of crop biomass and of grain at harvest are shown in Figure 6. Contrary to simulation results of crop biomass and grain yield, the

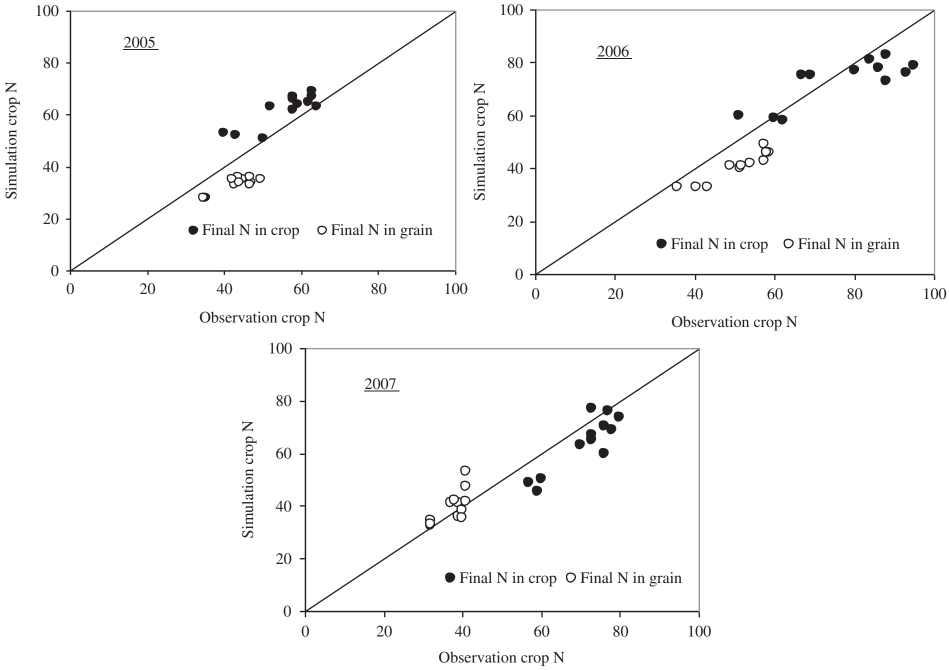


**Figure 6.** Evaluation of CERES rice model for N content in final aboveground biomass and grain under different N rates and water-saving regimes.

model could not simulate the N content of both crop biomass and grain satisfactorily in 2005. Grain N content was underestimated in all treatments. No increase was observed in the N content of grain by increasing the N application rate. However, this was not the case for N content of total crop biomass. In 2006, the N content of grain was again underestimated by the model but the simulated N content of grain responded positively to the N applied. The simulated N content of crop biomass was more evenly distributed around the 1:1 line although the model underestimated the values of this trait at high N applications. In 2007, a general good fit was obtained between simulated and measured N content of grain but the simulated values did not respond positively to the N applied. The model underestimated the N content of crop biomass although the simulated N content of biomass increased by increase in the N application rate.

Figure 7 compares simulated with measured N content of crop biomass (Figure 7A) and grain at harvest (Figure 7B) for all calibration and validation data set. The RMSE was 9 kg N $ha^{-1}$ and normalized RMSE was 20% for measured N content of grain. The N content of crop biomass was with a RMSE of 9 kg N $ha^{-1}$ and normalized RMSE 12% for measured N content of crop biomass. The linear regression between simulated and measured values had a slope $\alpha$ close to 1, an intercept β that was relatively small, and an $R^2$ larger than 0.85 for all variables, indicating a close correlation between the simulations and the measurements.

Pathak et al. (2004) reported good agreement, especially for grain N uptake, with RMSE of 21 kg $ha^{-1}$, in India. Godwin et al. (1990) and Buresh et al. (1991) reported predicted crop N uptake of 40–145 vs. observed uptake of 35–150 kg N $ha^{-1}$ in the Philippines. Timsina et al. (1998) reported that both observed and simulated total crop

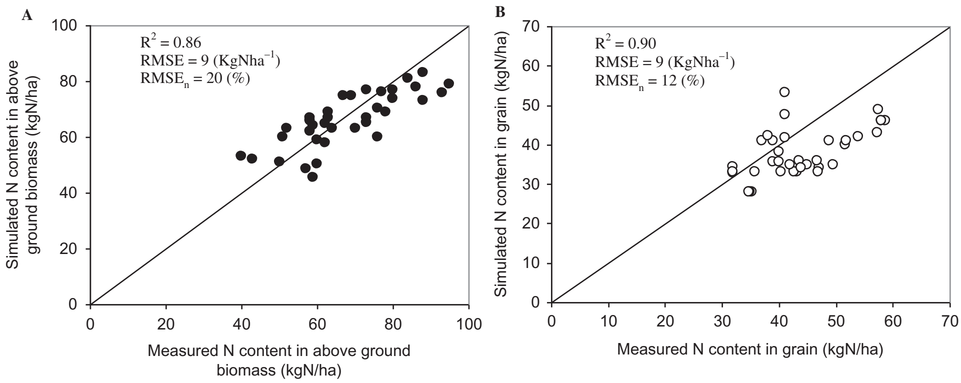


**Figure 7.** Simulated versus measured N content of grain (A) crop biomass (kgN ha$^{-1}$) (B) from data set 2005–2007.

N uptake by two rice cultivars ranged from 48 to 175 kg ha$^{-1}$, with absolute RMSE of 17 kg ha$^{-1}$ in northern Bangladesh, while version 4.0 in southern Australia predicted total biomass and N uptake were within 3% of the observed values, but N partitioning between straw and grain was poor (Meyer et al. 1994).

## Conclusion

The results from this study showed that the CERES rice model generally predicted grain, biomass yields, grain N uptake, and total N uptake fairly satisfactorily across a range of data sets covering varying levels of water- and N-management during 3 years in northern Iran. The performance of model was, however, better for N-added treatments than zero-N treatments. This may be due to error in estimating partitioning coefficients or errors in prediction of soil water that leads to lower N leaching losses than observed values and greater N uptake by the crop and hence greater crop biomass. The CERES rice model is calibrated and validated using field experimental data, and can be used to predict the experimental results of irrigation and N conditions in northern Iran, thus helping to identify target domains and irrigation- and N-management recommendations for farmers.

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