Evaluation of, and yield gap analysis in rice using, CERES Rice ver. 4.0 in northwest India

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Abstract

Observations from rice field experiments at three sites in northwest India (New Delhi, Ludhiana and Modipuram) were used to calibrate and validate the recently released version 4.0 of CERES Rice. The model performed satisfactorily in terms of grain yield and N uptake when compared against data from field experiments with a range of water and N management treatments across the three locations (root mean square of 0.82 Mg ha^{-1} and 8.5 kg ha^{-1} for grain yield and N uptake, respectively and d-stat of 0.94 for both traits). The model was used to analyse the gaps between potential and actual yields at the three locations. Potential yields ranged from 10.0 to 10.8 Mg ha^{-1} across the three locations, compared with research station yields of 6.2 to 7.8 Mg ha^{-1} and farmer average yields of 3.3 to 5.6 Mg ha^{-1}. The results suggest that there is plenty of scope to increase farmers' yields by improving crop management.

Media summary

Rigorously evaluated CERES Rice ver. 4.0 can help identify gaps between on-farm, research station and potential rice yields.

Key words

Potential yield, simulation, model calibration and validation

Introduction

Despite large research efforts to lift rice yields, there are large gaps between biologically and climatically achievable potential yields and research station and on-farm yields in the Indo-Gangetic Plain of south Asia (Aggarwal et al. 2000; Pathak et al. 2003). This is true even in the high-yielding environment of northwest India where the Green Revolution has dramatically increased yields of rice and wheat since the late 1960s. Research addressing the issue of yield gaps and identifying factors responsible for those gaps is important both for increasing food security and national revenue and for increasing resource-use efficiency and sustainability. Crop growth simulation models provide the means to quantify the effects of climate, soil and management on crop growth, productivity and sustainability of agricultural production. These tools can reduce the need for expensive and time-consuming field experimentation and can be used to analyse yield gaps in various crops including rice. CERES-Rice is a process-based, management-oriented model that can simulate the growth and development of rice as affected by varying levels of water and nitrogen (Ritchie et al. 1998). The model can identify gaps between potential and on-station and on-farm yields. Earlier versions of the model have been evaluated across rice-growing environments of Asia and their performance has been generally satisfactory but variable (Timsina and Humphreys 2003). However, the latest version (ver. 4.0) embedded within DSSAT 4.0 has not yet been evaluated. Before applying a model to examine real world problems, it needs to be rigorously evaluated under a range of environments. The objectives of the present study were to evaluate CERES-Rice ver 4.0

for its ability to simulate crop growth, yield, and N and water losses, and (2) to estimate potential yield and identify yield gaps for three locations in northwest India.

Methods

Sites and experiments used for model evaluation

Observations from rice field experiments conducted on a loamy sand (New Delhi), sandy loam (Ludhiana) and loam (Modipuram) were used to calibrate and validate CERES Rice ver. 4.0. All three sites are on alluvial soils of the Indo-Gangetic Plain, in a semi-arid sub-tropical climate with mean annual rainfall of 750-800 mm, 75 to 80% of which falls during the rice season. Mean maximum temperatures over the rice season at all three sites are similar (34-35?C over July to October), while the mean minimum is higher at Modipuram (24?C) compared with 18?C at the other two sites.

At Delhi the N management treatments included: 1) no added N (0N), 2) urea at 120 kg N ha^{-1} (120 N), and 3) urea plus farmyard manure (FYM) at 60 kg N ha^{-1} each. There were two water management treatments: 1) continuously saturated soil, and 2) three prolonged drying events (11-23 DAT, 30-48 DAT, and 57-78 DAT). During the drying events, the soil surface was allowed to dry until fine cracks developed, and the soil was kept at saturation at other times. A semi-dwarf, high-yielding variety (Pusa 44) with 120-130 days duration from sowing to maturity was grown at this site. Further details are presented in Pathak et al. (2002). At Ludhiana the N management treatments included: 1) 0N, 2) 120 kg N ha^{-1} as urea in 3 equal splits, and 3) 20 kg N ha^{-1} basal urea plus topdressing of 30 kg N ha^{-1} at a leaf colour chart (LCC) reading of 4. There were two water management treatments - irrigated 1 or 3 days after the disappearance of the floodwater. A semi-dwarf, modern, high-yielding variety (PR 114) with a duration 145 days was grown. At Modipuram N management for three cultivars, Basmati-370 (traditional tall, scented, duration 155 days), Saket-4 (inbred, semidwarf, duration 110 days), and Hybrid-6111 (hybrid, semidwarf, duration 130 days) was evaluated. Six fertilizer N (as urea) management treatments based on the LCC scores of ≤ 2, 3, and 4 (60, 120 and 160 kg N ha^{-1}) for Basmati-370 and ≤ 3, 4, and 5 (60, 120 and 160 kg N ha^{-1}) for Saket-4 and Hybrid-6111 were compared with two farmers' N rates (120, and 150 kg N ha^{-1}) and a 0N control. The soil was maintained at saturation throughout the experiment.

Model evaluation and application

Model evaluation comprised of calibration, validation and sensitivity analysis. In CERES Rice genetic coefficients for different cultivars are used as model inputs to describe crop phenology in response to temperature and photoperiod (Hunt and Boote 1998). The coefficients for the cultivars in this study were estimated from independent field experiments with irrigated and N-fertilized treatments (Pathak et al. 2002; AK Shukla, unpublished data; Bijay-Singh, unpublished data) by adjusting the coefficients until close matches were achieved between simulated and observed phenology and yield. Rice yield was simulated using soil and daily weather data (solar radiation, maximum and minimum temperatures, and rainfall) from meteorological observatories located at each site. Simulation results were validated against the observed data from treatments that were not used for calibration. The root mean square error (RMSE) and index of agreement (d-stat) (Willmott 1982) were used for model validation.

Potential yields (average of 20 years) of the most important rice varieties in each of the 3 regions - Pusa 44 (Delhi), PR 114 (Ludhiana), and Saket 4 (Modipuram), were simulated by switching "Off" water and N in the simulation control section of File X. The district average grain yields of rice for each region were collected from the Fertilizer Association of India Regional Statistics (FAI 2000), New Delhi.

Results

Model calibration and validation

The juvenile phase coefficient (P1), photoperiodism coefficient (P2R) and grain filling duration coefficient (P5) of the cultivars varied from 650 to 980 degree days (?C), 180 to 295 degree days h^{-1}, and 330 to 720 degree days (?C), respectively. Because of its longer duration basmati rice had the highest juvenile phase and grain filling duration coefficients. The critical photoperiod (P20) was 12 hours for all cultivars.

Simulation of cumulative N mineralized during the rice crop of 16-18 kg ha^{-1} was much lower than the generally observed values of 50-80 kg N ha^{-1} (Pathak and Sarkar 1994). Therefore the values for the parameter SLNF (N mineralization rate) of 3.7, 2.2 and 2.0 for Delhi, Ludhiana, and Modipuram, respectively, were used to increase cumulative mineralization in the unfertilised treatment to 45-60 kg N ha^{-1}.

Predicted grain yields agreed well with observed yields (RMSE=815 kg ha^{-1}; d-stat=0.94) (Fig. 1). There was, however, generally poor prediction of yields in the unfertilised treatments. Removing the unfertilised treatments from the analysis improved the relationship (RMSE=643 kg ha^{-1}; d-stat=0.94). The agreement between simulated and observed total dry matter yields was also reasonable, but not as good as for grain yields (RMSE=3330 kg ha^{-1}; d-stat=0.75). There was reasonably a good agreement between observed and simulated N uptake by rice especially for grain N uptake at Delhi (RMSE=8.5 kg ha^{-1}; d-stat=0.94) (Fig. 2).

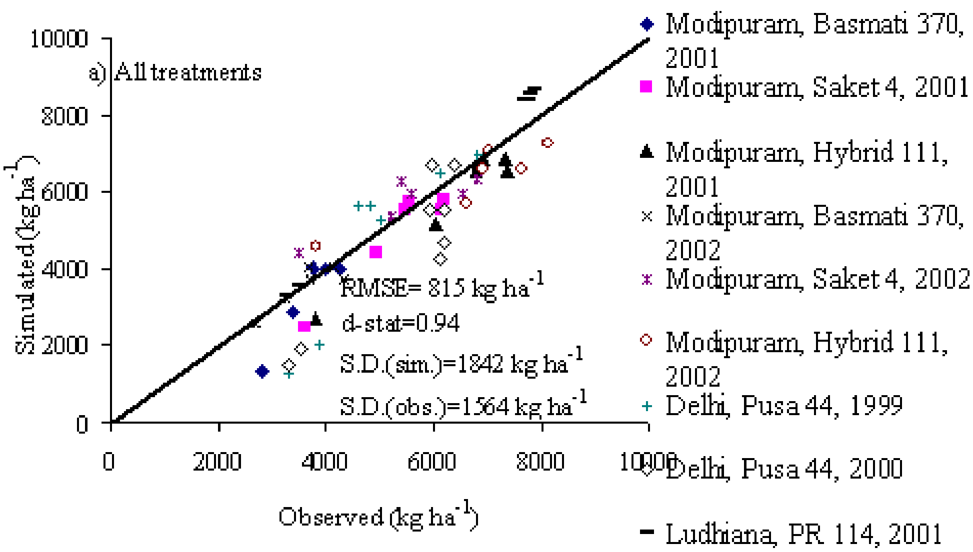

Fig. 1. Simulated and observed grain yields of rice

Yield gap analysis

Simulated average potential yield at the 3 sites ranged from 10.0 to 10.8 Mg ha^{-1} (Table 1). Yield was highest at Ludhiana because of higher solar radiation, while the lower yield at Modipuram was due to lower solar radiation and higher daily minimum temperature resulting in decreased photosynthesis, increased respiration, and shortened vegetative and grain filling periods (Horie et al. 1995). Pathak et al. (2003) estimated similar potential yields of rice using CERES Rice V 3.0 for various locations in NW India.

Table 1. Potential, on-station and on-farm yields (Mg ha^{-1}) and yield gaps in rice for three sites in India.

Site	Potential yield[a]	Actual yield	Yield gap (%)

		On-station[a]	On-farm[b]	On-station[a]	On-farm[b]
Ludhiana	10.8	7.8	5.6	28	48
Delhi	10.3	7.1	3.3	31	68
Modipuram	10.0	6.2	3.5	38	65

[a]PR114, Pusa 44 and Saket 4 used for potential (average of 20 years) and on-station yields at Ludhiana, Delhi and Modipuram, respectively.
[b]District average yield

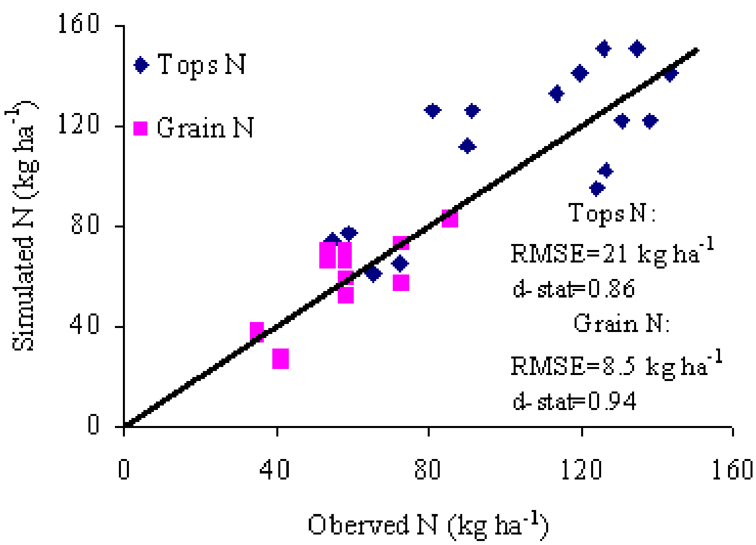

Fig. 2. Simulated and observed N uptake by rice (cultivar Pusa 44) in Delhi in 1999 and 2000

The highest on-station yield occurred at Ludhiana (7.8 Mg ha^{-1}) and the lowest at Modipuram (6.2 Mg ha^{-1}) (Table 1). The higher yield at Ludhiana occurred despite lower soil fertility (SOC 0.40%) than at Modipuram (SOC 0.54%) and Delhi (SOC 0.44%) and the same amount of applied N (120 kg ha^{-1}). Earlier transplanting (mid to end of June) and higher solar radiation (Pathak et al. 2003) resulted in higher yield at Ludhiana. On-farm average yields of rice varied from 3.3 Mg ha^{-1} at Delhi to 5.6 Mg ha^{-1} at Ludhiana (Table 1). More favourable climate, better irrigation facilities and better socio-economic conditions of the farmers are major reasons for the higher yields at Ludhiana.

The results indicate wide gaps between potential, research station and farmer yields. The gaps between potential and research station yields ranged from 28 to 38% of potential yield, or 3.0 to 3.8 t/ha (Table 1). The gap between potential and on-farm yields was even greater (48-68%) at all locations. Simulation models can be used to explain the causes of yield gaps. Further research is required to identify those causes and biophysical and socio-economic approaches to raising yields and reducing the gaps.

Conclusions

The RMSE and d-stat values revealed the satisfactory performance of CERES Rice ver. 4.0 in predicting grain yield and N uptake for a range of water, N management and cultivars across 3 locations in northwest India. There are large gaps between potential, research station and on-farm yields. There is plenty of scope to increase farmers' yields by improving crop management, and research needs to focus on increasing yield and resource-use efficiency. Simulation models, such as CERES Rice, in conjunction with socio-economic research, could be an effective approach for achieving this, but rigorous evaluation is needed before models can be used to inform the development of guidelines and policy for sustainable cropping systems.

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