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Evaluation of CERES-Wheat and CropSyst models for water–nitrogen interactions in wheat crop

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ABSTRACT

Crop simulation models can provide an alternative, less time-consuming and inexpensive means of determining the optimum crop N and irrigation requirements under varied soil and climatic conditions. In this context, two dynamic mechanistic models (CERES (Crop Environment REsource Synthesis)-Wheat and CropSyst (Cropping Systems Simulation Model)) were validated for predicting growth and yield of wheat (*Triticum aestivum* L) under different nitrogen and water management conditions. Their potential as N and water management tool was evaluated for New Delhi representing semi-arid irrigated ecosystems in the Indo-Gangetic Plains. The field experiment was carried out on a silty clay loam soil at the Research Farm of the Indian Agricultural Research Institute, New Delhi, India during 2000–2001 to collect the input data for the calibration and validation of both the models on wheat crop (variety HD 2687). The models were evaluated for three water regimes [I4 (4 irrigations within the growing season), I3 (3 irrigations within the growing season) and I2 (2 irrigations within the growing season)] and five N treatments (N_0, N_{60}, N_{90}, N_{120} and N_{150}). Both the models were calibrated using data obtained from the treatments receiving maximum nitrogen and irrigations, i.e., N_{150} and I4 treatments. The models were then validated against other water and nitrogen treatments. For performance evaluation, in addition to coefficient of determination (R^2), root mean square error (RMSE), mean absolute error (MAE) and Wilmot's index of agreement (IoA) were estimated. Both CERES-Wheat and CropSyst provided very satisfactory estimates for the emergence, flowering and physiological maturity dates. For CERES-Wheat overall prediction (pooled result of the three water regimes) of grain yield was satisfactory with significant R^2 values (0.88). The model, however, under estimated the biomass under all water regimes and N levels except for N_0 level, under which biomass was overpredicted. CropSyst predicted yield and biomass of wheat more closely than CERES-Wheat. The combined RMSE for the three water regimes between predicted and observed grain yield was 0.36 Mg ha^{-1} for CropSyst as compared to 0.63 Mg ha^{-1} for CERES-Wheat. Similarly, RMSE between observed and predicted biomass by CropSyst was 1.27 Mg ha^{-1} as compared to 1.94 Mg ha^{-1} between observed and predicted biomass by CERES-Wheat. Wilmot's index of agreement (IoA) also indicated that CropSyst model is more appropriate than CERES-Wheat in predicting growth and yield of wheat under different N and irrigation application situations in this study.

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1. Introduction

Mechanistic models are very helpful in deciding the best management options for optimizing crop growth and yield. If pests and diseases are controlled, yield of any crop in a given environment mainly depends upon irrigation and fertilizer nitrogen (N) management. Both water and nitrogen are subjected to losses by many pathways if not managed properly. Therefore, there is a considerable interest in technologies that enhance nitrogen use efficiency and productive use of applied irrigation water leading to increased productivity. Field experiments for quantifying optimal crop N and water requirement are time-consuming, requiring many years of trials at multiple locations. Experimental results are used to develop general fertilizer recommendations for the whole region although experiments are conducted on a smaller scale. These recommendations consequently cannot take into account factors like soil and weather variability across locations (Mathews and Blackmore, 1997). Crop simulation models consider the complex interactions between weather, soil properties and management factors (water and N) that influence crop performance. Thus, these models can help synthesize much of the information accumulated from the various experiments at diverse locations and provide a reliable alternative for extrapolating this information to other regions of interest, with different soil–climatic characteristics (Mathews and Blackmore, 1997). Simulation of various crop and fertilizer management strategies using such models can, therefore, lead to better fertilizer decision-making (Godwin and Jones, 1991; Paz et al., 1998, 1999).

CERES (Crop Environment REsource Synthesis)-Wheat (Ritchie et al., 1988; Godwin et al., 1989; Singh et al., 1991) is a process-based, management-oriented model that can simulate the growth and development of wheat as affected by varying levels of water and nitrogen (Ritchie et al., 1998). The CERES-Wheat model simulates crop growth, development and yield taking into account the effects of weather, genetics, soil (water, carbon and nitrogen), planting, irrigation and nitrogen fertilizer management. CERES-Wheat is available to users as part of the DSSAT (Decision Support System for Agrotechnology Transfer), which is a suite of crop models that have a common soil water and nitrogen component enabling crop rotation simulation and designed to estimate production, resource use, and risks associated with crop production practices (Tsuji et al., 1994; Jones et al., 1998).

CropSyst (Cropping Systems Simulation Model) is a multi-year, multi-crop, daily time step crop growth simulation model, developed with emphasis on a friendly user interface, and with a link to GIS software and a weather generator (Stockle et al., 1994, 2003; Stockle and Nelson, 1999). Unlike DSSAT, CropSyst uses the same approach to simulate the growth and development of all herbaceous crops. To reach this aim, simplifications have been introduced to describe some processes, e.g., monolayer canopy; constant specific leaf area (SLA), absence of daily assimilates partitioning. This makes CropSyst easier to calibrate with a reduced set of crop parameters as compared to the CERES model which is very detailed in describing crop physiology requiring more number of crop parameters. These aspects and the possibility of simulating rotations make CropSyst a useful tool for large-scale simulations (Confalonieri and Bechini, 2004). On the contrary, the level of detail in CERES is useful in drawing attention to gaps in understanding, interpreting data from field experiments in different environments (Monteith, 1996) and studying the processes at the level of plant components (Confalonieri and Bechini, 2004), that involve more complex calibration process with more number of parameters (Stockle, 1992; Monteith, 1996). This detailed input data set required by the CERES model in simulating plant growth, is an impediment for its extensive use (Mahmood, 1998). This is particularly true when large-scale simulations are needed because of the elevated number of parameters required by the larger spatial variability.

The ability to simulate wheat yield by CERES-Wheat has been evaluated in a wide range of environments across the world. Kovács et al. (1995) reported satisfactory results in studies to evaluate the capacity of the CERES-Wheat model as a tool to simulate grain yields, N uptake, and nitrate accumulation in the soil through many years of variable weather and soil conditions in Hungary. Bowen and Papajorgji (1992) reported satisfactory simulations of the effect of N fertilizer on winter wheat yields in Albania. Timsina et al. (1998) used CERES-Wheat and rice (*Oryza sativa* L.) models for modeling cultivar, N, and moisture effects on rice–wheat sequence cropping system in Bangladesh. However, reports on validation and evaluation of CERES-Wheat model under different water and N availability conditions in semi-arid and subtropical regions are very few (Pathak et al., 2006). This emphasizes the importance of validating the model (with refinements if needed) in this environment for its wider application. Reports on validation of CropSyst for wheat growth and yield under Indian conditions are scanty. Hence, a need was felt to validate the CropSyst model under various management situations. Though performance evaluation under different N management conditions has been reported (Roberto et al., 2006) but it was not evaluated under different N and water interaction conditions. It was also observed that a comparative evaluation for CERES-Wheat and CropSyst models has not been carried out for wheat yield simulation, although CERES-Maize was compared with CropSyst by Jara and Stockle (1999), for simulation of water uptake and by Clemente et al. (2005) for simulation of yield and biomass of maize.

The present study was carried out with the main objective of validation and performance evaluation of the detailed CERES-Wheat model as well as the less detailed CropSyst model under varying N levels and water regimes.

2. Materials and methods

2.1. Model description

2.1.1. CERES-Wheat

The CERES-Wheat model simulates phenological development of the crop; growth of grains, leaves, stems, and roots; biomass accumulation based on light interception and environmental stresses; soil water balance; and soil N