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Identifying irrigation and nitrogen best management practices for aerobic rice–maize cropping system for semi-arid tropics using CERES-rice and maize models

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ABSTRACT

Research based development of best management options for aerobic rice–maize cropping systems must be developed to improve water and nitrogen use efficiency. The main objective of this study was to identify water saving rice production technology for rice grown in sandy loam soils in semi-arid conditions using the calibrated CERES-Rice and Maize models of the Decision Support System for Agro Technology Transfer (DSSAT). A two-year experiment with two different crop establishment methods viz., aerobic rice and flooded rice with four nitrogen rates followed by maize under zero tilled conditions was used to calibrate and evaluate DSSAT CERES-Rice and CERES-Maize models. The calibrated models were used to develop best management options for an aerobic rice–maize sequence which can produce similar yields with water savings relative to that of traditional flooded rice–maize system. The results showed that application of 180 kg N ha^{-1} in four splits and automatic irrigation with 40 mm, when soil available water (ASW) in top 30 cm fell below to 60% was the best management combination for aerobic rice, saving 41% of water while producing 96% of the yield attainable under flooded conditions. Similarly for maize, application of 120 kg N ha^{-1} and irrigation with 30 mm of water at 40% ASW in the top 30 cm soil was the most dominant management option. Further, application of 180 kg N ha^{-1} with rice followed by 120 kg N ha^{-1} in maize provided stable yield for both aerobic and flooded rice systems over time as simulated by the model. The results illustrate that DSSAT model is a useful tool for evaluating alternative management options aimed at maintaining yields and saving water in rice–maize systems in semi-arid regions.

1. Introduction

Rice–maize double cropping (R–M) is the most important emerging cropping system in South Asia. R–M systems currently occupy around 3.5 M ha in Asia (Timsina et al., 2010). The growing water shortage conditions for continuous rice cultivation have prompted studies to look for alternate rice-based cropping systems. The development of short duration rice varieties coupled with high yielding maize hybrids provide an opportunity for increasing the area under R–M cropping in this region (Timsina et al., 2010; Buresh and Haefele, 2010). Both crops in R–M systems require high nutrient input in view of the respective large grain and by-product yields that require high amounts of nutrient extraction from soils. Hence, strategies that optimize nutrient management need to be developed for R–M systems with an aim to supply adequate fertilizers to meet crop requirement while minimizing the nutrient losses and maximizing nutrient use efficiency. Field experiments conducted in R–M sequences usually focus either on rice or maize independently without considering the influence of the previous crop and its associated growing conditions. Stand establishment in maize, typically planted immediately after rice in R–M systems, is influenced to a great extent by soil moisture content and soil physico-chemical conditions after rice. However, cropping system based field experiments for quantifying optimal crop N and water requirements are time consuming, requiring extensive numerous resources and years to draw valid conclusions.

Crop simulation models consider the complex interactions among crop, weather, soil and management factors that influence crop performance. These models are useful for supplementing

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field experiments for identifying best management strategies in a cropping sequence using soil and weather parameters (He et al., 2012). Crop growth models such as those in Decision Support System for Agro technology Transfer (DSSAT) have been used successfully in many places around the world for a wide range of conditions and applications (Tsuji et al., 1998; Jones et al., 2003; Hoogenboom et al., 2010). The DSSAT is a package of 26 crop growth models derived from DSSAT-CROPGRO and CERES models that use the soil, weather and crop management files to predict the crop growth and yield (Jones et al., 2003; Hoogenboom et al., 2010). CERES (Crop Estimation through Resource and Environment Synthesis)-Rice and -Maize are process-based models embedded in DSSAT simulate the main processes of crop growth and development such as phenological development, canopy leaf area growth, dry matter accumulation and grain yield. The CERES-Rice and -Maize models were evaluated by many researchers across locations (Sarkar and Kar, 2006; Timsina and Humphreys, 2006; O'Neal et al., 2002; Behera and Panda, 2009; Liu et al., 2011; He et al., 2012; Salmerón et al., 2012; Jeong et al., 2014; Ngwira et al., 2014) with good agreements between predicted and observed values. Even though simulation results generally will have some uncertainties associated with inputs and model parameters, but still the simulation models can be effectively utilized as a scientific tool to increase the resource use efficiency of cropping systems (Timsina and Connor, 2001; Sarkar and Kar, 2008; Timsina and Humphreys, 2006; Timsina et al., 2008). None of the previous studies have, however, included rice and maize yield predictions in response to changes in rice establishment methods-switching from a traditional flooded to a water saving aerobic rice method and the associated N and water balances. In addition, long term studies on alternate irrigation management practices in rice–maize systems (R–M systems) with an aim to reduce water requirements have not been conducted. Therefore, our study was done with the following main objectives to: (1) evaluate the DSSAT cropping system model for prediction of soil water, N balance, rice and maize yields in response to methods of rice establishment and N rates in R–M cropping system, and (2) determine best management options to increase water productivity of aerobic R–M system for semi-arid tropics using long term weather data.

2. Materials and methods

2.1. Experimental site

Field experiments were conducted from 2009 to 2011 at the experimental farm of Acharya NG Ranga Agricultural University, Hyderabad, India. The experimental site was located in the Southern Telangana Agro climatic zone of Andhra Pradesh, India (17°19′N, 78°28′E and 534 m above mean sea level). The physico-chemical characters of the sandy loam soil at the experimental site are presented in Table 1. The climate of the area is semi-arid in nature with annual rainfall of 850 mm, 80% of which is received during the south west monsoon period (June–October).

2.2. Treatment details

Rice and maize crops were grown in a rice-fallow-maize-fallow sequence. Rice was grown during the monsoon season from July to October and maize was grown in the dry season from November to March. The experiment was described in detail by Kadiyala et al. (2012). Briefly, the experimental design was a split plot with rice establishment methods as the main plots and four N rates as sub-plot treatments. The two rice establishment methods were aerobic rice (AR) and flooded rice (FR) and the four N treatments were 0, 60, 120 and 180 kg N ha^{-1}. Nitrogen was applied in three equal split rates, at the time of planting, at maximum tillering and at panicle initiation stages in both aerobic and flooded plots. A popular high yielding low land rice variety MTU 1010, was selected for both aerobic and flooded methods. Rice seeds were directly sown in rows 22.5 cm apart in the first week of July for AR treatments. The AR was irrigated with 50 mm of water whenever the soil moisture tension in the top 10 cm reached −30 kPa using Delta-T Devices-ML2 capacitance probes. In FR treatments, a seedling nursery was planted on the same day that the AR crop was planted. After 30 days, seedlings were transplanted at a hill spacing of 20 × 15 cm with two seedlings per hill. After rice harvest, maize, DeKalb 800 M hybrid, was planted at a spacing of 60 × 20 cm under no- till conditions. Rice crop was harvested to the ground without leaving any residue except the roots. The post rainy season maize crop was irrigated with 50 mm water whenever the ratio of irrigation water to cumulative pan evaporation (IW/CPE) reached 1.0. Maize crop received 120 kg N, 26 kg P and 33 kg K ha^{-1}. Fertilizer N was applied in three split doses- at the time of sowing, at knee height stage and at silking, whereas entire P and K amounts were applied at the time of planting. Pests, diseases and weeds were intensively controlled during the crop growth period.

2.3. Measurements

Weather data (maximum and minimum temperatures, rainfall, and sunshine hours) were taken from the meteorological observatory at Agricultural Research Institute (ARI), Rajendranagar, Hyderabad located approximately 100 m away from the experimental plots. The daily bright sunshine hours were converted to solar radiation (MJ m^{-2} day^{-1}) using the DSSAT Weatherman conversion that uses the Angstrom Formula (Allen et al., 1998). Soil parameters such as soil texture, soil pH, bulk density, drained upper (DUL) and lower moisture limits (DLL), hydraulic conductivity and organic carbon were estimated using International pipette method (Piper, 1966), Beckman pH meter (Jackson, 1967), core sampler method, pressure plate apparatus, constant-head method and Wet digestion method (Walkley and Black, 1934), respectively. Crop

Table 1
Physical and chemical properties of the experimental plot used in model evaluation and application.

Depth	LLV (cm^3 cm^{-3})	DUL (cm^3 cm^{-3})	SAT (cm^3 cm^{-3})	SRGF	BD (g cm^{-3})	SOC (%)	Clay (%)	Sand (%)	Silt (%)	pH	CEC (cmol kg$^{-1)}$
0–15	0.13	0.23	0.42	1.00	1.37	0.51	33.4	53.6	13	8.0	26.9
15–30	0.15	0.24	0.43	0.90	1.42	0.48	35.4	53.6	11	8.2	18.0
30–45	0.14	0.26	0.42	0.70	1.56	0.34	33.4	59.6	7	8.2	13.3
45–60	0.08	0.23	0.36	0.30	1.53	0.14	25.4	65.6	9	8.1	9.0
60–75	0.10	0.24	0.37	0.10	1.44	0.31	31.4	60.6	8	8.1	8.4
75–90	0.13	0.23	0.38	0.02	1.56	0.04	21.4	69.6	9	8.2	5.1
90–105	0.08	0.26	0.40	0.01	1.59	0.08	27.4	65.6	7	8.2	6.6
105–120	0.08	0.24	0.41	0.01	1.49	0.08	21.4	67.6	11	8.2	6.9
120–135	0.09	0.24	0.40	0.01	1.69	0.11	21.4	76.6	2	8.4	5.5
135–150	0.08	0.20	0.38	0.01	1.52	0.07	18.4	75.6	6	8.5	4.7

LL: lower limit; DUL: drained upper limit; SAT: saturation; SRGF: relative root distribution; BD: bulk density; SOC: soil organic carbon.