Increasing rainfed rice productivity in Central Java, Indonesia: a modeling approach

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Abstract

The typical rainfed cropping system in Central Java includes a dry-seeded rice crop grown from November to February (*gogorancah*), followed by a transplanted rice crop from March to June (*walik jerami*). This study assessed the climatic and agrohydrologic constraints to rice production and explored management strategies to increase the yield and yield stability of the double-rice cropping system using the crop growth simulation model ORYZA2000. The model was parameterized and evaluated using eight seasons of field experiments from 1995 to 2000 in Jakenan Experiment Station. The root mean square error between simulated and measured grain yields is considered low (10-20%). Simulation of potential and rainfed rice yield was carried out on a 15-d planting interval for the period 1977-2000. The average simulated potential yield of *walik jerami* rice was higher than that of *gogorancah* rice, indicating that radiation and temperature are not determinants of the observed relatively low yields of *walik jerami* rice. Simulated rainfed yields of *walik jerami* crops declined sharply if planted later than early March. Deep tillage, additional N fertilizer, and supplemental irrigation increased the yields of rainfed *walik jerami* crops. The results highlight the importance of timely planting and management to increase rice yields and yield stability in the area.

Media summary

This simulation study indicates the importance of critical transplanting dates and the potential of using tillage and nutrient management and on-farm reservoirs to increase rainfed rice yields in Central Java.

Key Words

Simulation modeling, deep tillage, agronomic N use efficiency, water productivity

Introduction

Rainfed lowland rice in Central Java covers about 295,000 ha (Amien and Las 2000). In this area, farmers practice a high degree of crop intensification. At the onset of the rainy season, a dry-seeded rice (*gogorancah*) crop is grown. Immediately after the harvest of dry-seeded rice, a second, transplanted rice (*walik jerami*) crop is grown under minimum tillage in submerged conditions. Earlier studies showed that the average yield of *gogorancah* rice is 3.5–6.5 Mg ha^{-1}, whereas *walik jerami* yields are only 1.2–3.0 Mg ha^{-1} (Mamaril et al 1994, Wihardjaka et al 1999). The quantitative effect of rainfall, solar radiation, and temperature on yield of both *gogorancah* and *walik jerami* crops in Central Java has yet to be determined.

We hypothesize that several management strategies can alleviate the effect of drought and increase rice yields. Planting dates of both the *gogorancah* and the *walik jerami* crops can be adapted so that the combined yields are maximized. Tillage can be adapted to modify soil hydraulic properties and improve root distribution and growth and soil water extraction. The effect of additional fertilizer in rainfed systems may also be explored. The recent introduction of on-farm water reservoirs offers scope for supplemental irrigation to alleviate drought during the reproductive stage of the *walik jerami* crop.

This study uses the ecophysiological crop growth model ORYZA2000 (Bouman et al 2001)

- to assess the climatic and agrohydrological (groundwater depth) constraints to rainfed rice production in Central Java, and
- to explore the efficacy of various management strategies aimed at increasing yield and yield stability of the double-rice cropping system.

Methods

Field experiments

Two sets of field experiments at the Jakenan Experiment Station ($6^o45'$ S, $111^o10'$ E, 7 m above sea level) were used to calibrate and evaluate the ORYZA2000 model. In the first experiment (April-July 1995 and March-July 1996), the experimental treatments were laid out in a split-plot design with four replications using two water levels (irrigated and rainfed) in the main plot and two tillage treatments in the subplots. The tillage treatments were shallow tillage (hoed once to 10-cm depth) and deep tillage (hoed twice to 30-cm depth). The water retention characteristics of soils following the shallow and deep tillage treatments were determined using the wind method, pressure plate assembly, and hanging water column. Soil hydraulic conductivity following shallow and deep tillage treatments was determined *in situ* using the column method. In the second experiment (six cropping seasons, December 1997-May 2000), the treatments were laid out in split-plot design with two water treatments (irrigated and rainfed) in the main plot and five fertilizer treatments (0-22-90, 120-22-0, 120-0-90, 120-22-90 (recommended), 144-27-108 kg NPK ha^{-1}) in the subplots in four replications.

Twelve hill samples (0.27 m^2) were taken from each subplot at 15, 30, and 45 d after sowing, at panicle initiation, flowering, and grain-filling stages for aboveground biomass and its partitioning. At physiological maturity, 22 hills (0.50 m^2) were sampled to determine biomass, its partitioning, and yield components. Rice yield was determined from 6-m^2 sampling areas. Groundwater table depth was measured daily using 5-cm-diameter, 150-cm-long PVC tubes in each main plot of rainfed treatments.

Model simulations

Following experiment-specific parameterization (calibration of crop phenology, indigenous soil nitrogen supply, and percolation), three series of simulation runs were made. In the first series, ORYZA2000 was evaluated using the experiment data in eight crop seasons of 1995-2000. The second series of simulations explored long-term rice yield under potential and rainfed conditions. In rainfed conditions, three water table scenarios were constructed from the measurements in eight crop seasons: shallow (mean-standard error (se)), medium (mean), deep (mean+se) water table. The third simulation series focused on the effect of tillage (shallow, deep), fertilizer management (0, 60, 120, 144 kg N ha^{-1}), and supplementary irrigation (scenarios I_1=irrigation applied when moisture of the topsoil falls below field capacity, I_2=daily irrigation with 7.5 mm from panicle initiation (PI) to maturity (M), and I_3=daily irrigation with 3.3 mm from PI to M).

Results

Model evaluation

The scatter diagrams (Figure 1) show a high degree of association between simulated and measured aboveground biomass (correlation coefficient, r = 0.95) and grain yield (r=0.89). Simulation of biomass has a root mean square error of prediction (rmse) of 25.71%, which is considered fair, and yield simulation has an rmse of 16.41%, which is good. The relatively low rmse and the high r indicate the adequacy of the model to satisfactorily simulate aboveground biomass and grain yield.
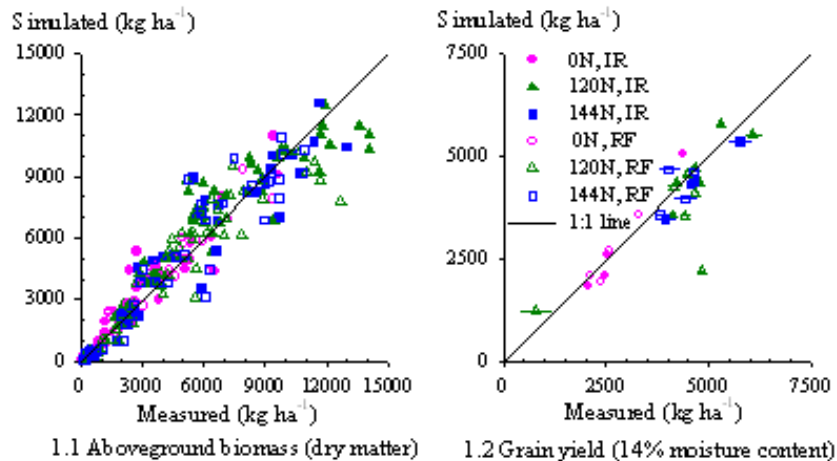
Figure 1. Scatter diagram of simulated and measured (mean?se) aboveground biomass (1.1) and grain yield (1.2) for three N levels (0, 120, 144 kg N ha^{-1}) in irrigated (IR) and rainfed (RF) conditions in Jakenan.

Yield exploration

The potential yields (expressed at 14% moisture content) ranged from 3.8 to 5.5 Mg ha^{-1}, depending on the date of seeding. Rice sown in the typical *gogorancah* period (November-December) had a lower potential yield (on average 3.8 Mg ha^{-1}) than rice planted in the typical *walik jerami* period (February-March, average yield = 4.2 Mg ha^{-1}). The lower potential yield in the *gogorancah* period is the consequence of low radiation levels during the grain filling stage.
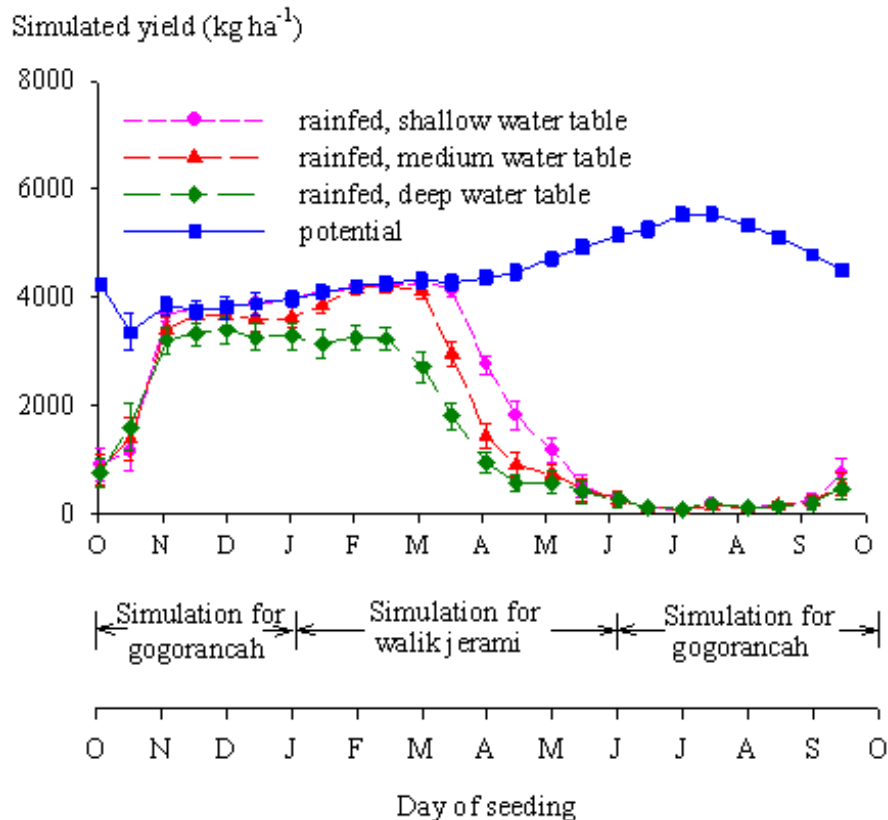
**Figure 2. Simulated potential and rainfed rice yield (mean?se) in Jakenan, Central Java, Indonesia.**

The yield of rainfed rice sown from early November to mid-March under shallow tillage with 120 kg N ha^{-1} differed significantly among the three water table depth scenarios. During this period, rainfed yields reached the potential level with the shallow water table but were lower with deep water tables. For crops sown at the end of the rainy season and in the dry season (roughly April-September), the yield was very low for all three water table scenarios. Low yields of late-sown crops were mainly due to drought stress.

Management options to increase yield

Grain yields of rainfed crops grown in deep tillage conditions were higher than those under shallow tillage in mid-December-January and in March-May (Figure 3.1). The higher yields under deep tillage is the consequence of more moisture available through capillary rise.

In rainfed conditions, simulated grain yield in fields with no additional N fertilizer ranged from 0.8 Mg ha^{-1} for crops sown in mid-April to 2.8 Mg ha^{-1} for crops sown in early February. Yield increase from an additional 60 kg N ha^{-1} was lower than that of 120 and 144 kg N ha^{-1} for crops sown from mid-February to early March (Figure 3.2). Yield increase due to additional N declined sharply for crops sown from early March onward.

For crops sown in the typical *walik jerami* period (March-April), simulated yields in irrigation scenarios I_1, I_2, and I_3 were about 0.2-3.2, 0.2-2.0, and 0.1-1.2 Mg ha^{-1} higher, respectively, than the simulated yields under rainfed conditions. Irrigation water requirements for crops sown in the *walik jerami* period in scenario I_1 varied from 45 to 344 mm, while for scenarios I_2 and I_3 they were fixed at 275 and 120 mm, respectively. The yield increase per cubic meter of irrigation water applied in the three irrigation scenarios is presented in Figure 3.3. The maximum yield increase in the three scenarios occurred for crops sown in early April. For crops sown from mid-April onward, the yield increase in scenarios I_1 and I_2 were higher than that in scenario I_3.
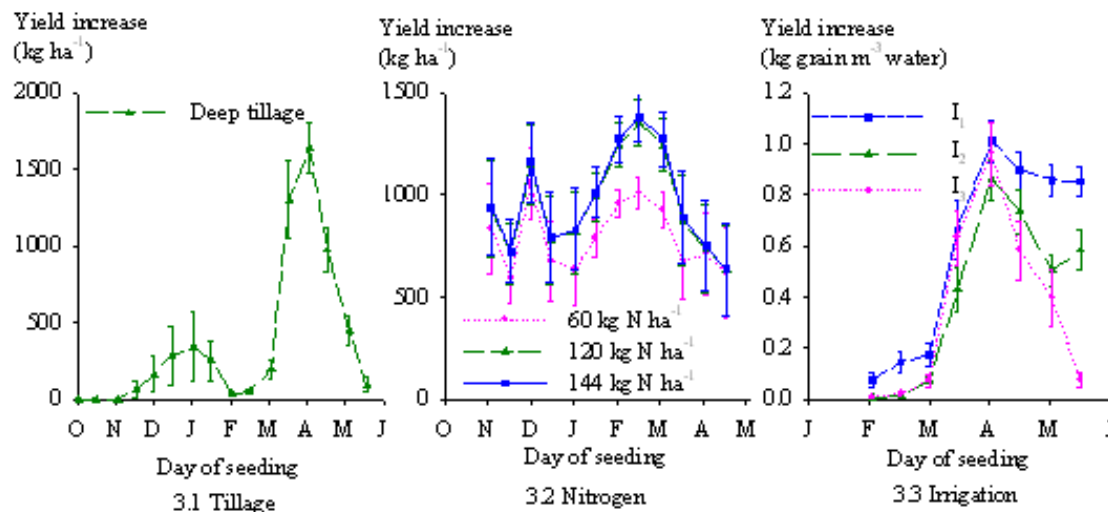
Figure 3. Simulated yield increase for deep tillage (3.1; basis shallow tillage), three N levels (3.2; basis zero-N application), and three irrigation scenarios (3.3; basis rainfed) for rice planted in Jakenan.

Conclusions

- The ORYZA2000 model adequately simulated aboveground biomass and grain yield of irrigated and rainfed lowland rice in the study area.

- The simulated potential yield of *walik jerami* rice was higher than that of *gogorancah* rice due to the higher radiation levels during the grain filling period.
- Simulated yields of rainfed crops sown from early November to mid-March differed significantly among the three water table depth scenarios. Rainfed yields reached the potential level with the shallow water table but were lower with deep water tables. The yield difference is caused by water deficits particularly during the later part of the rainy season.
- Simulated rainfed yields of *walik jerami* crops declined sharply if planted later than early March. The decline in yields of *walik jerami* rice with late planting indicates the importance of identifying the critical transplanting dates in different water table depth situations.
- Deep tillage, additional nitrogen, and supplementary irrigation have potential for increasing yields of rainfed rice in the study area. The magnitude of the yield gains from these management practices, and the associated resource (N, water) use efficiency changed with the time of crop establishment.
- Simulation models such as ORYZA2000 are useful tools, complementing experimental work, in exploring wide-range management strategies for various conditions in rainfed lowland rice research.

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