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Developing ORYZA 1N for Medium- and Long-Duration Rice: Variety Selection under Nonwaterstress Conditions

Dillip Kumar Swain,* Srikantha Herath, Burla Chandra Bhaskar, Prameela Krishnan, Kurkuri Srinivasa Rao, Sangram Keshari Nayak, and Rabindra Nath Dash

ABSTRACT

There is a need to increase the rice production in nonwaterstressed rice-growing areas during the wet season in Asia by the use of a suitable combination of a medium- or long-duration variety and appropriate nutrient management strategy. The crop growth simulation model ORYZA 1N was used for variety selection and N optimization in nonwaterstress conditions. Selection was made from 12 released rice varieties of 115 to 150 d duration. The model was calibrated using input data from field experiments that were conducted during the wet season (June–November) of 2001 at the Central Rice Research Institute, Cuttack, India. In the medium-duration varieties (115–130 d), there was good agreement between simulated and observed leaf area index, biomass, and grain yield. The simulated biomass of long-duration varieties (135–150 d) showed large deviation from observed biomass at flowering. In the wet season of 2000, the model accurately predicted the grain yield, biomass, and leaf area index of medium- and long-duration varieties. When the ORYZA 1N model was used to simulate the effect of planting dates on rice yield, it predicted the decline in yield with late planting. It was recommended that farmers consider planting new variety Ranjit in the favorable lowlands that do not have water stress during the wet season and should apply 80 kg N ha^{-1} in four equal splits at transplanting, active tillering, panicle initiation, and flowering. Technology verification trials of this practice conducted during the wet season of 2002 produced 5.51 Mg ha^{-1} of rice, compared with 4.36 Mg ha^{-1} grown with the conventional practices of area farmers.

Rice yield is closely related to type of rice cultivation, which is largely affected by water regimes. Rice ecosystems are roughly classified into irrigated, rainfed lowland, upland, and floodprone. Rainfed lowland rice is defined as the rice grown in bunded paddies without irrigation water; it occupies about 25% (36 million ha) of the world rice area. Rainfed rice is important particularly in South and Southeast Asia. The average yield is only 2.3 Mg ha^{-1} (Cooper and Wade, 1999). Scobie et al. (1993) estimated that 21% of the extra rice production required by the year 2030 would have to come from the rainfed lowlands. To understand how to affect such an increase in rice in rainfed lowlands, it is important to better understand factors controlling yields. With the estimated incident total solar radiation of 12.57 MJ m^{-2} d^{-1} during the wet season in the tropics, the stagnant maximum yield for the high-yielding rice varieties is 10 Mg ha^{-1} (Peng et al., 2000), although rice cultivar Takanari produced over 11 Mg ha^{-1} of grain yield in 2000 in Japan (Takai et al., 2005).

It is common to have maximum daily temperatures from 35 to 41°C during the hot months in tropical Asia. At these temperatures, a heat-susceptible variety may suffer from a high percentage of sterility (Satake and Yoshida, 1978). The most critical time for heat-induced sterility is during anthesis. Susceptible varieties are damaged when the heat occurs at anthesis. Tolerant varieties can survive temperatures up to 39°C (Yoshida, 1981). Especially at higher levels of N, high temperatures also seem to reduce the efficiency at which N produces spikelets. Warm temperatures enhance tillering, and low night time temperature (16–21°C) and late ripening favors grain production, giving more time for grain filling (De Datta, 1981).

As optimum crop production becomes more complex, involving fertilizer, pest control, genotype, environment, and cultural practices, conducting trials that take all these factors into account becomes increasingly complex and expensive. A suitably validated crop simulation model could be used to test hundreds of such combinations in a brief time at limited expense. Such simulations can adequately describe relative trends in yields caused by environment variation (Penning de Vries et al., 1989). Information such as this is valuable for cultivar selection for the farmers' fields in several locations (Palanisamy et al., 1993). Simulations also could be an essential step in defining the yield gap between farmers' yields and potential yields, assisting efforts to bridge the gap. Several comprehensive mechanistic and detailed process-based rice models, such as SIMRIW (Horie, 1987), CERES-RICE (Godwin et al., 1990), ORYZA1 for potential production (Kropff et al., 1994), ORYZA_W for water-limited production (Wopereis et al., 1996), ORYZA-N for nitrogen (N)-limited production (Drenth et al., 1994), ORYZA 1N (Aggarwal et al., 1997), and ORYZA 2000 (Bouman et al., 2001) are available. Model simulations frequently assume the rice yield is not reduced by diseases, pests, and weeds. Recently, Aggarwal et al. (2006a, 2006b) developed and evaluated InfoCrop, a generic and dynamic crop model based on several ear-

D.K. Swain, Agricultural and Food Engineering Dep., Indian Inst. of Technology, Kharagpur, Kharagpur 721 302, India; S. Herath, Environment and Sustainable Development, United Nations Univ., Tokyo 150 8925, Japan; and B.C. Bhaskar, P. Krishnan, K.S. Rao, S.K. Nayak, and R.N. Dash, Central Rice Research Inst., Cuttack 753 006, India. Received 12 July 2006. *Corresponding author (swain@agfe.iitkgp.ernet.in).

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677 S. Segoe Rd., Madison, WI 53711 USA

Abbreviations: DVRI, crop development rate during photoperiod-sensitive phase; DVRJ, crop development rate during the basic vegetative phase; DVRP, crop development rate during panicle development phase; DVRR, crop development rate during the grain filling phase; DVS, development stages; FLV, fraction of shoot dry matter allocated to leaves; FSO, fraction of shoot dry matter allocated to storage organ; FST, fraction of shoot dry matter allocated to stems; FSTR, fraction of stem reserves; HU, heat units; LAI, leaf area index; NFLV, nitrogen fraction in leaves; SLA, specific leaf area.

lier models that included the effects of pests and diseases for several crops, including rice. ORYZA 1N (based on ORYZA-N) was evaluated using data from several field experiments (Aggarwal et al., 1997; Singh et al., 2003). However, ORYZA 2000 (based on ORYZA 1, ORYZA_W, and ORYZA N) simulates the water balance and crop growth and development of lowland rice under potential, water-limited, and N-limited conditions.

Bachelet and Gay (1993) compared the performance of four rice crop simulation models and determined that ORYZA1 and CERES-RICE simulated more realistic responses to temperature than RICEMOD (Mc Mennamy and O'Toole, 1983) and RICESYS (Graf et al., 1990). It is reasoned that a model containing details of processes at the leaf level would be appropriate where much of the knowledge of CO_2 and temperature effects on growth processes are available (Matthews and Wassmann, 2003). Although ORYZA 2000 was tested under conditions of limiting water (Boling et al., 2000) and N (Bouman and van Laar, 2006) separately, it has not been validated for conditions of combined water and N limitations. Under conditions of no water and no nitrogen stress, the model ORYZA 1 is called from the subroutine models of ORYZA 2000 that simulates the growth and development of rice. Under conditions of N limitation, the ORYZA 1 with N balance modules of ORYZA 2000 model is called. Among several simulation models, ORYZA1 is very suitable for theoretical evaluation of rice plant types under well watered conditions.

Wade (1995) suggested that the use of simulation models could not be divorced from the experimental process. For example, results of simulations may show places where it is necessary to conduct further experiments so as to test the predictions or further improve the model. The results of simulation are sensitive to input values of several parameters. Uncertainty in these parameters can affect the reliability of simulated yields. How far the ORYZA model series has been calibrated for simulation of long-duration rice varieties (135–150 d) is not known. These varieties have different morphology and height than medium-duration (115–130 d) varieties. These tall (>1.0 m), long-duration varieties usually have less tillering and lower N responsiveness than high-yielding, medium-duration, semi-dwarf varieties (Tanaka et al., 1964; Wada and Sta Cruiz, 1989; De Datta and Broadbent, 1990; Wada and Sta Cruiz, 1990; Sta Cruiz and Wada, 1994). The objectives of this study were to use a simulation model and systems analysis techniques for variety selection and N optimization to attempt to boost rice yields in a rainfed ecosystem where water stress does not exist.

MATERIALS AND METHODS

Field Experiment

Field experiments were conducted at the research station of the Central Rice Research Institute in Cuttack (20°40′ N, 85°38′ E; elevation 30 m), India, during the wet season (June–December) of 2000 and 2001. The soil of the site is classified as an Ultisol and is made up of 65.5% sand, 15.6% silt, and 18.8% clay, with a bulk density of the surface soil (0–0.15 m) 1.4 Mg m^{-3}, a pH of 5.8, an organic C content of 6.7 g kg^{-1}, and a total N content of 0.7 g kg^{-1}. The native soil fertility of the experimental site was rated medium based on organic C content (Ramammorthy and Bajaj, 1969). The following five medium-duration and seven long-duration rice varieties were used: medium-duration (115–130 d), IR 36, Mahamaya, Kranti, Lalat, and Khitish; and long-duration (135–150 d), Mahsuri, Madhuri, Savitri, Rajshree, Swarna, Sashi, and Ranjit.

In the wet season of 2000, the experiment with 12 rice varieties was laid out in a randomized design with two replications at 80 kg N ha^{-1}. In the wet season of 2001, the experiment was laid out in a split-plot design with two replications where varieties were in main plot and four N levels (0, 40, 80, and 120 kg N ha^{-1}) were in sub plots. The total amount of N was divided into four equal splits and was applied as urea at basal, active tiller initiation, panicle initiation, and flowering stages of the crop in both the years. Phosphorus and potassium were applied at the rate of 26 kg P and 50 kg K ha^{-1}, respectively, to the puddle soil at planting. Rice seedlings were transplanted when they were 30 d old (on 20 July 2000 and 14 Aug. 2001); two seedlings were planted per hill. The plant-to-plant spacing was 0.15 m, and the row-to-row spacing was 0.2 m. Plots remained flooded up to 0.3 m with rain water throughout the experiment. Weeds, diseases, and insects were strictly controlled throughout the growth periods in both years. Plant samples of all varieties were collected at five growth stages: transplanting, active tillering, panicle initiation, flowering, and maturity. For this purpose, nondestructive observations on tiller numbers of 10 hills in each side (total 40 hills) of a plot, leaving two border rows, were recorded, and the average number of tillers of a representative hill was established (Thyagarajan et al., 1995). From these 40 hills, six representative hills are considered as sample hills. After collection, the plant samples were cleaned and washed in distilled water to remove surface contamination and separated into stems (leaf sheath + stem), leaves, and panicles. The leaf area was determined soon after the hills were collected. From each hill, the second longest tiller was selected as the sample tiller. The area of all the leaves of the sample tillers was measured with a leaf area meter (LA-3000A; LI-COR, Lincoln, NE). The dry weight of the sample tillers' leaves and the rest of the leaves were determined separately, and the leaf area index (LAI) was calculated (Yoshida et al., 1976). Samples were oven dried at 80°C to remove moisture and stop enzymatic reactions. Each sample was periodically turned over and weighed, and drying was terminated when constant weight was reached. Leaf samples were powdered in a porcelain basin to homogenate and a subsample was analyzed for N content using the micro-Kjeldahl distillation method (Yoshida et al., 1976).

The Model

The ORYZA 1N model (Aggarwal et al., 1997) was used in this study. This is a modification of the basic ORYZA 1 model, with added components for available soil N supply and the N uptake efficiency from the applied fertilizer. The N components were from ORYZA-0 (ten Berge et al., 1994) and ORYZA-N (Drenth et al., 1994). The main difference between ORYZA 1 and ORYZA1N is that the latter includes N uptake and allocation to plant organs. This is similar to the ORYZA 2000 model when the water limitation does not exist and to the water balance model when ORYZA_W is switched off. The model describes crop growth and development as affected by solar radiation and temperature. The model follows the daily calculation scheme for the rates of dry matter production of the plant organs and the rate of phenologic development. By integrating these rates over time, dry matter production of the crop is simulated throughout the growing season.

The basic input requirements of the model are similar to that of ORYZA1. Inputs include latitude; daily weather data (radiation, minimum, and maximum temperature); plant density; date of crop emergence and transplanting; and cultivar-specific, morphophysiologic characteristics of the plant species. The additional input requirements of the ORYZA 1N model are the N supply that included the indigenous N from soil–flood water system and N applied from the fertilizer, which is similar to that of ORYZA-N component of ORYZA 2000 model. It assumes that a constant amount of indigenous N is added to the soil N pool every day. Although N uptake is sensitive to soil type, climate, and management practices, the N recovery efficiency increases from a relatively lower value from basal N application at transplanting to higher recoveries at panicle initiation. The N fertilizer application was provided as an input table corresponding to the date and amount of N application. The model interpolates fertilizer N amounts on each day of simulation between two relevant dates.

Model Calibration

Input parameters for ORYZA 1N were derived from the data sets of the field experiments during the wet season of 2000 and 2001 for model calibration and verification. Weather inputs, such as maximum and minimum temperature, total global solar radiation, vapor pressure, and wind speed, were measured daily at a weather station 500 m from our test plots. Environmental requirements for the model include latitude, longitude, elevation, daily weather data (irradiance and minimum and maximum temperatures), date of sowing, date of transplanting, and the amount of N application and the date it was applied.

The following variety-specific input parameters were derived (Kropff et al., 1994) (Table 1 and Fig. 1–3).

Relative Growth Rate of Leaf Area Development (RGRL): The RGRL was estimated from the slope of relationship between ln(LAI) and the temperature sum when LAI is <1.

$$\mathrm{RGRL} = [\ln(\mathrm{LAI})t_2 - \ln(\mathrm{LAI})t_1]/[\Delta \text{ degree days}]$$

Degree days are in degrees Celsius. For the rice heat unit (degree day) calculation, base temperature (T_{base}) was 8°C, optimum temperature (T_{opt}) was 30°C, and maximum temperature (T_{high}) was 42°C. For temperatures below the base temperature or above the maximum temperature, the rate of development is zero. The heat units (HU) for a day (°Cd d^{-1}) are calculated from the mean daily temperature (T_d) (Kropff et al., 1994) as:

$$T_d \le T_{base},\ T_d \ge T_{high}: \mathrm{HU} = 0$$

$$T_{base} < T_d \le T_{opt}: \mathrm{HU} = T_d - T_{base}$$

$$T_{opt} < Td < T_{high}: \mathrm{HU} = [T_{opt} - (T_d - T_{opt}) \times (T_{opt} - T_{base})/(T_{high} - T_{opt})]$$

The values of the following parameters were computed from the dry weight of plant organs as suggested by Kropff et al. (1994).

Fraction of shoot dry matter allocated to leaves (FLV):

$$\mathrm{FLV} = [(\text{leaf wt})t_2 - (\text{leaf wt})t_1]/[(\text{shoot wt})t_2 - (\text{shoot wt})t_1]$$

Fraction of shoot dry matter allocated to stems (FST):

$$\mathrm{FST} = [(\text{stem wt})t_2 - (\text{stem wt})t_1]/[(\text{shoot wt})t_2 - (\text{shoot wt})t_1]$$

Fraction of shoot dry matter allocated to storage organ (FSO):

$$\mathrm{FSO} = [(\text{panicle wt})t_2 - (\text{panicle wt})t_1]/(\text{shoot wt})t_2 - (\text{shoot wt})t_1]$$

Fraction of stem reserves (FSTR):

$$\mathrm{FSTR} = (\text{maximum stem wt at flowering} - \text{stem wt at final harvest})/(\text{maximum stem wt})$$

Spikelet growth factor (SPGF): The SPGF (number kg^{-1}) was computed from the slope (λ = spikelet formation factor) of the relationship between spikelet number m^{-2} at flowering and

Table 1. A dozen rice varieties were grown in the wet season of 2001 at Cuttack, India and obtained these growth parameters that were then used to calibrate the ORYZA 1N model.†

Variety	RGRL × 10^3	FSTR × 10	DVRJ × 10^4	DVRP × 10^4	DVRR × 10^3	SPGF	WGRMX
	°C d^{-1}		°C d^{-1}			no. kg^{-1}	mg grain^{-1}
			Medium-duration				
IR-36	7.545 ± 0.195	2.295 ± 0.049	8.16	6.28	1.837	74 737 ± 1862	24.38
Mahamaya	7.448 ± 0.194	1.775 ± 0.050	7.86	6.28	1.840	53 755 ± 1266	30.65
Kranti	8.170 ± 0.224	3.840 ± 0.083	8.49	6.28	1.831	71 496 ± 1816	28.20
Lalat	6.983 ± 0.177	2.258 ± 0.058	6.88	6.29	1.864	59 101 ± 1459	25.00
Khitish	7.488 ± 0.193	2.143 ± 0.064	7.86	6.28	1.840	74 766 ± 1591	21.15
Mean	7.5268	2.4622	7.85	6.28	1.842	66 771	25.88
			Long-duration				
Mahsuri	7.573 ± 0.154	1.035 ± 0.028	4.37	6.31	1.979	53 431 ± 1464	18.20
Madhuri	7.555 ± 0.154	0.735 ± 0.022	4.56	6.29	1.963	70 250 ± 2096	20.45
Savitri	7.900 ± 0.218	2.680 ± 0.065	3.57	6.48	2.147	61 106 ± 1651	21.23
Rajshree	7.170 ± 0.165	0.495 ± 0.011	4.77	6.25	1.955	50 209 ± 1338	21.40
Swarna	7.533 ± 0.194	2.198 ± 0.054	4.29	6.31	1.988	58 828 ± 1274	20.60
Sashi	7.228 ± 0.164	1.645 ± 0.043	4.47	6.30	1.973	51 386 ± 1395	23.20
Ranjit	7.830 ± 0.229	3.280 ± 0.089	4.04	6.37	2.037	68 625 ± 1586	19.38
Mean	7.541	1.724	4.29	6.33	2.006	59 119	20.64
Grand mean	7.54	2.03	5.78	6.31	1.94	62 307	22.82
SD	0.33	0.98	1.89	0.06	0.10	9237	3.68

† DVRJ, crop development rate during the basic vegetative phase; DVRP, crop development rate during panicle development phase; DVRR, crop development rate during the grain filling phase; FSTR, fraction of stem reserves; RGRL, relative growth rate of leaf area development; SPGF, spikelet growth factor; WGRMX, maximum individual grain weight.

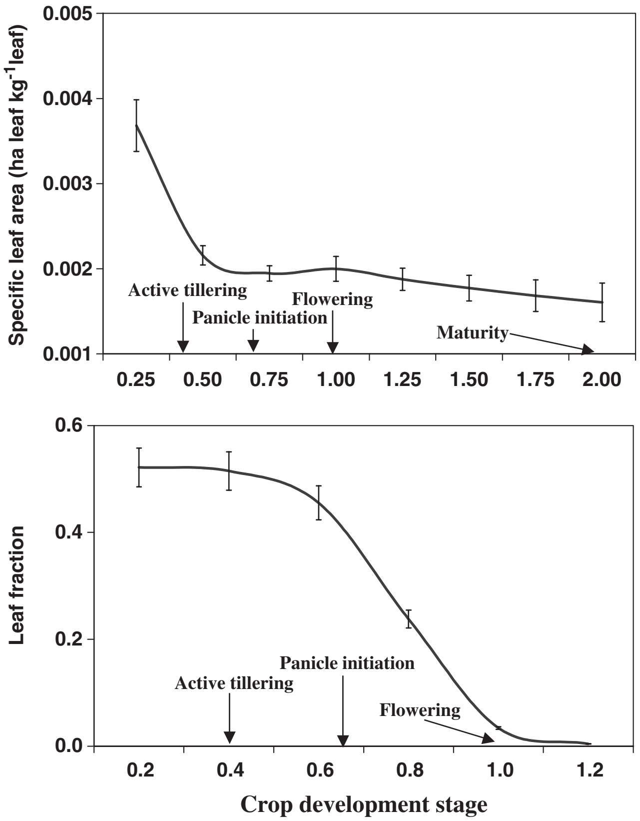

Fig. 1. Input parameter values for specific leaf area and fraction of shoot dry matter allocated to leaves as a function of crop development stages used to calibrate the ORYZA 1N model for medium- and long-duration rice varieties. Vertical lines indicate SD.

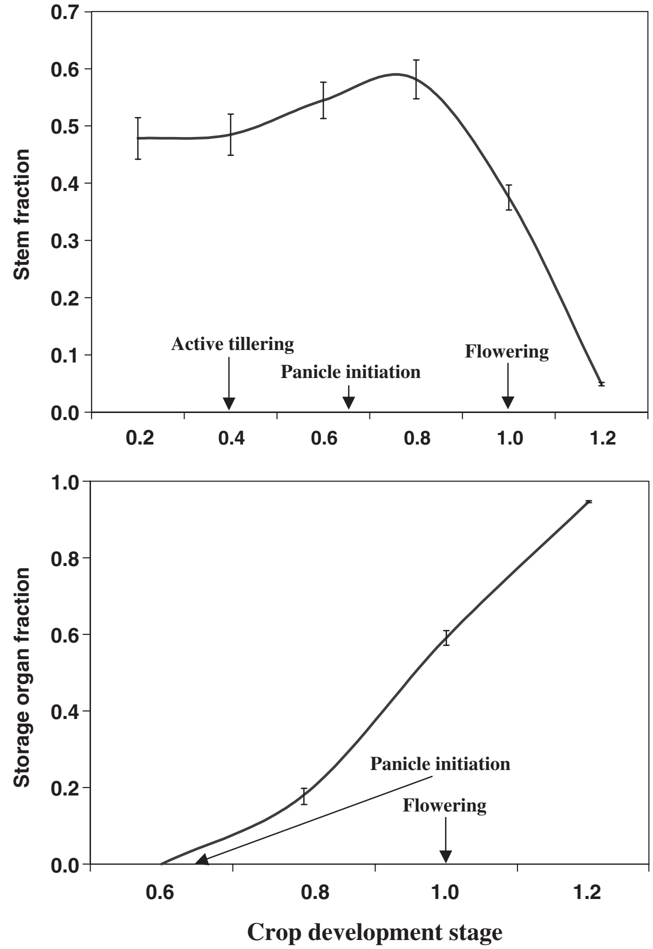

Fig. 2. Input parameter values for the fraction of shoot dry matter allocated to stems and storage organs as a function of crop development stages used to calibrate the ORYZA 1N model for medium- and long-duration rice varieties. Vertical lines indicate SD.

the growth (g m^{-2}) of the crop over the period between panicle initiation and flowering (Kropff et al., 1994).

WGRMX: Maximum individual grain weight (mg grain^{-1}) was determined at maturity from 200 randomly collected grain samples from each replication over all the N treatments of each variety.

$$\text{Specific leaf area (SLA)} = \text{(leaf area)/(leaf wt)}$$

and is expressed in ha leaf kg^{-1}.

$$\text{N fraction in leaves} = \text{(amount of N in leaf[g])} \text{/(leaf area[m}^2\text{])}$$

Parameterization

The life cycle of the rice crop is divided into four main phenologic phases:

Basic vegetative: From DVS (developmental stage) = 0 (seedling emergence) to DVS = 0.4 (start of photoperiod sensitivity)
Photoperiod sensitivity: From DVS = 0.4 (start of photoperiod sensitivity) to DVS = 0.65 (panicle initiation)
Panicle formation: From DVS = 0.65 (panicle initiation) to DVS = 1.0 (first flowering)
Grain filling: From DVS = 1.0 (first flowering) to DVS = 2.0 (physiologic maturity)

The values of the fraction of shoot dry matter allocated to leaves, stems, and storage organs, the SLA, and the N fraction in the leaves were calculated from the observed values at seedling emergence to maturity. Additional values of these parameters as a function of DVS were determined by iteration when observed values did not correspond to an equal spacing of the DVS. For this purpose, the values at the emergence (DVS = 0) were taken from the reported values of Kropff et al. (1994). Newton's general interpolation formula, further improved by Aitken (Sastry, 1983), was used to generate intermediate sets of values for these parameters from higher-order interpolation. The formula was able to generate five values for FLV and FST up to flowering and eight values of SLA up to maturity. The lack of variation between medium- and long-duration varieties for FLV, FST, FSO, and SLA did not warrant separate grouping, so the mean values were reported (with SD) for all varieties across all N levels (Fig. 1 and 2).

Values of NFLV as a function of DVS for each variety and N levels were generated from observation and interpolation. The variation of the NFLV values among N levels was great, so it was shown for each N level (Fig. 3). The extent of variation among the members of each group of varieties (medium or long) was small. The variation between two groups of varieties was large enough to present them separately. Therefore, mean NFLV values for medium- or long-duration varieties for each N level with a SD in relation to DVS was depicted (Fig. 3).

When the graph of the input parameters was plotted against DVS, the curves of the data sets were smoothed (constant first

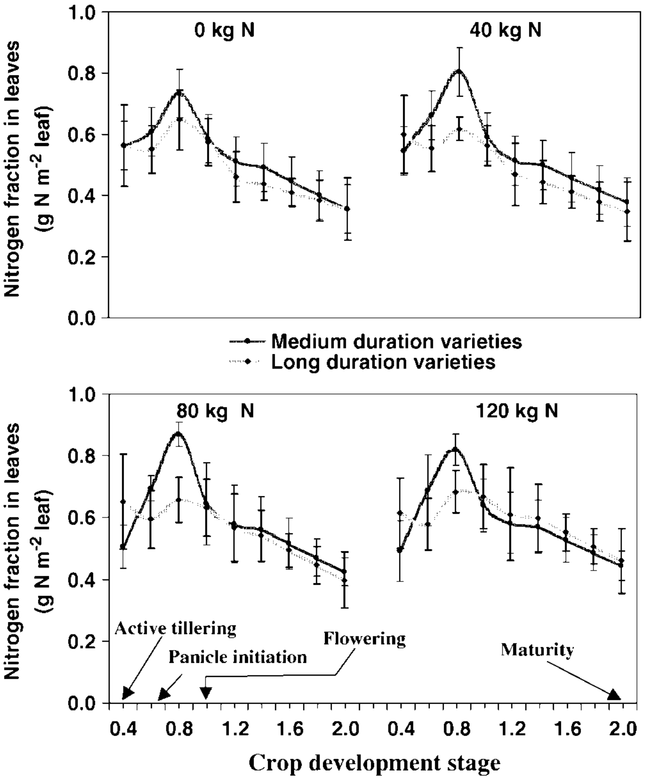

Fig. 3. Variation in N fraction in leaves as a function of crop development stages used to calibrate the ORYZA 1N model for medium- and long-duration rice varieties. Vertical lines indicate SD.

derivative) to eliminate unwanted fluctuations. The dates of sowing, transplanting, panicle initiation, flowering, and maturity for each genotype in each experiment were used to determine the specific pre- and post-flowering development rates using the program DRATES (Kropff et al., 1994). The crop development rates used were DVRJ: crop development rate during the basic vegetative phase (°C d)$^{-1}$; DVRI: crop development rate during the photoperiod-sensitive phase (°C d)$^{-1}$; DVRP: crop development rate during the panicle development phase (°C d)$^{-1}$; and DVRR: crop development rate during the grain-filling phase (°C d)$^{-1}$ (Table 1). In the model, N fertilizer efficiency increased linearly from 35% from N applied basally at transplanting to 75% by broadcast application at the panicle initiation stage. The N uptake rate was 8 kg N ha^{-1} d^{-1} (Aggarwal et al., 1997). The indigenous soil N supply of the experimental sites was 0.45 kg N ha^{-1} d^{-1} based on the estimated average from a large number of experiments (Panda et al., 2004; Swain et al., 2006).

Simulation

The LAI and dry matter production of each variety at all N application levels during the wet season of 2001 were simulated and averaged separately for medium- and long-duration groups at active tillering, panicle initiation, and flowering and maturity stages. A paired *t* test was used to compare observed and simulated grain yield of all varieties at all N application levels (Panse and Sukhatme, 1954). The weather conditions differed between 2000 and 2001. Tests were performed to see what influence that difference would have on LAI, biomass, and grain yield of the rice crop.

The rank order of each rice variety was determined from the simulated and observed yield of 2001. Duncan's multiple range test was used to find which values were significantly different (Gomez and Gomez, 1984).

The ORYZA 1N model was used to simulate grain yield of the same 12 rice varieties in 1997, 1998, and 1999. We used the variety-specific input parameters to simulate the effect of three separate planting dates (15 July, 30 July, and 15 August) at four N rates (0, 40, 80, and 120 kg N ha^{-1}). The variety-specific input parameters derived from the treatment showing optimum response to applied N in the field experiment of 2001 were used for all N levels.

Formulation and Test of New Technology

Farmers in the area of our study grow high-yielding rice varieties of 140 to 150 d duration during wet seasons. However, they are not satisfied with available rice varieties and desire greater yield, better quality, and lower pest and disease infestation. The released high-yielding rice varieties have not been evaluated at this site. Therefore, it was necessary to test the new technology, which consists of newer varieties, increased levels of N, and more precise timing of N application. The crop simulation model was used to help farmers determine not only the best variety choice for the conditions on their individual farms but also the best planting date and N rates to use and when to apply them.

A technology verification trial (Gomez and Gomez, 1984) was conducted in farmers' fields during the wet season of 2002 to compare the new technology based on model simulations with farmer's rice-production practices. The site is a rainfed area of 6 km^2 in the village of Kasiadihi in the district of Dhenkanal, which is in the state of Orissa, India. Its climate is hot and humid. The weekly mean maximum/minimum temperature ranged from 26/12°C in December to 41/26°C in April. The predominant soil is a sandy clay loam (15% clay, 72% sand, and 13% silt) with a pH of 5.2. The organic C content was 5.5 g kg^{-1}, total N content was 0.7 g kg^{-1}, and the fertility status of soil is rated medium based on organic C content (Ramammorthy and Bajaj, 1969). The bulk density of the surface soil (0–0.15 m) was 1.45 Mg m^{-3}.

The district's annual rainfall averages 1421 mm (SD 262 mm), with about 81% of it falling during the June–September monsoon (Directorate of Agriculture and Food Production, 2003). Rainfall variation is low during the monsoon months, and the water stress is normally transitory during this period. The average number of rainy days is 73 yr^{-1}.

The trials to verify this new technology involved three test components, each at two levels, and were conducted in a $2^3 = 8$ factorial experiment design. The three test components are variety, N rate, and N timing of application. The two levels of each test component represent (i) recommended (model simulation) practice of new technology and (ii) the farmer's practice. The following three sets of treatments were tested (Table 2):

1. Set X, consisting of two treatments: The new technology (the test factors are all at new technology level) and the farmer's practice (the test factors are all at farmer's level).
2. Set Y, consisting of five treatments (number of test factors + 2): The two treatments of set X plus the three (number of test factors) intermediate treatments, each of which represents a treatment combination in which all the test factors but one are at the new technology level.
3. Set Z, consisting of a 2^3 complete factorial treatment combination.

Because the number of treatments is smallest in set X and largest in set Z, the proportion of the number of test farms for

Table 2. Treatment sets X, Y, and Z of the technology verification trial for rice conducted during the wet season of 2002 in the farmers' fields at the village Kasiadihi, Dhenkanal district, India, involving three test factors: variety, N rate, and splits/timing of application each at the level of recommended practice of new technology and farmers practice.

Treatment set	Treatments†
X (new technology and farmer's practice)	1. RV + RL + RT
	2. FV + FL + FT
Y (two treatments of set X plus three intermediate treatments where all test components but one are at new technology level)	1. RV + RL + RT
	2. RV + RL + FT
	3. RV + FL + RT
	4. FV + RL + RT
	5. FV + FL + FT
Z (complete factorial treatment combination involving three test components each at two levels)	1. RV + RL + RT
	2. RV + RL + FT
	3. RV + FL + RT
	4. RV + FL + FT
	5. FV + RL + RT
	6. FV + RL + FT
	7. FV + FL + RT
	8. FV + FL + FT

† FL, farmer's N rate; FT, farmer's N timing of application; FV, farmer's variety; RL, recommended N rate; RT, recommended N timing of application; RV, recommended variety.

treatment sets X, Y, and Z was restricted to nearly 3:1:1 as commonly used for technology verification trials (Gomez and Gomez, 1984). Two replications per farm have been taken to reduce experimental error.

The test farms were widely separated and of much different sizes. The previously grown crops and the physical and biological environments of the farms also varied. However, they experienced similar weather conditions. Aside from the differences described in the following paragraph, all other cultural practices and plant protection measures were the same as those normally used by other farmers in the same areas as each of our test farms. Plots were set up on the land of 13 participating farmers, whose farms ranged in size from 0.4 to 1.0 ha. The X treatments (new technology and farmer's practice) were set up on eight test farms, the Y treatments (two treatments of set X plus three intermediate treatments where all test components but one are at new technology level) were set up on three farms, and the Z treatments (complete factorial treatment combination involving three test components each at two levels) were set up on the two largest farms, each with 1.0 ha. All treatments were randomized with two replications. Nurseries on each farm supplied the seedlings for that farm. Transplanting in all the farms was completed within 15 d starting from the model-recommended date of planting, using 25- to 30-d-old seedlings.

At physiologic maturity (when 80% panicles have 80% ripened spikelets having 18–22% moisture content in grains or the lower part of the panicle is in the hard dough stage), a 5-m^2 area was sampled to determine the total above ground biomass, panicles per m^2, grains per panicle, thousand grain weights, harvest index, and sterility (Yoshida et al., 1976). A 50-m^2 area was harvested at all sites to determine grain yield.

Data Analysis

The data were treated for yield gap analysis and combined ANOVA (Gomez and Gomez, 1984). The yield gap analysis measures the difference in any index of productivity between the new technology and farmers' practice and partitions this difference into components representing contributions from the individual test factors. The combined ANOVA was performed to evaluate the effect of uncontrollable environmental factors across the farms on crop response. Data on grain yield, biomass, and yield attributes of two test farms of Z set with two replications were used for the analysis. We measured the yield gap as the difference in grain yield between the new technology (the test factors are all at new technology level) and the farmer's practice (the test factors are all at farmer's level). Biomass and other yield attributes, wherever a treatment effect was significant, were considered for gap analysis. The gap was averaged for 13 test farms. The contribution of each test factor to the gap in yield, biomass, and yield attributes was determined.

RESULTS AND DISCUSSION

Model Calibration

Leaf Area Index

Simulated LAI for long-duration varieties was in good agreement with observed LAI at all N application rates and growth stages (Fig. 4). It also was close to observed LAI at all N application rates and growth stages of medium-duration varieties. The only exception was at panicle initiation stage, where the simulation overestimated the observed levels.

Biomass

Model simulations were satisfactory for medium- and long-duration varieties at all N rates in all of our tests (Fig. 5) because most of the simulated values lie within their corresponding observed values and their SDs. The simulated biomass of the medium-duration varieties was in close agreement with that observed at all but the highest N application rate at all growth stages. At an application rate of 120 kg N ha^{-1}, the simulated biomass remained similar to observed levels until panicle initiation and rose above them for the remainder of the growing season. Simulated biomass of the long-duration varieties at all N application rates was close to the observed biomass at all growth stages except flowering, where it was substantially less. Refinement of the model is required at later growth stages. Another possibility for model improvement would be the rate of CO_2 assimilation by light-saturated leaves, which can vary between 10 and 50 kg CO_2 ha^{-1} leaf h^{-1} for C_3 species and 10 to 90 kg CO_2 ha^{-1} leaf h^{-1} for C_4 species, depending on N concentration and temperature (Goudriaan, 1986; Van Keulen and Seligman, 1987). Peng et al. (1995) observed a positive and significant correlation between single-leaf net photosynthetic rate and leaf N content per unit leaf area of rice under field conditions. Compared with the relationship between single-leaf net photosynthetic rate under saturating light and leaf N content per unit leaf area as determined under greenhouse growth chamber conditions in previous studies, they observed higher leaf net photosynthetic rate for rice at low leaf N content under field conditions. When this field-derived relationship was used, the ORYZA 1 had improved simulations of dry matter. However, they did not report the effect on leaf area or grain yield. More fundamental insights are needed concerning relations between N in leaf and maximum rate of photosyn-

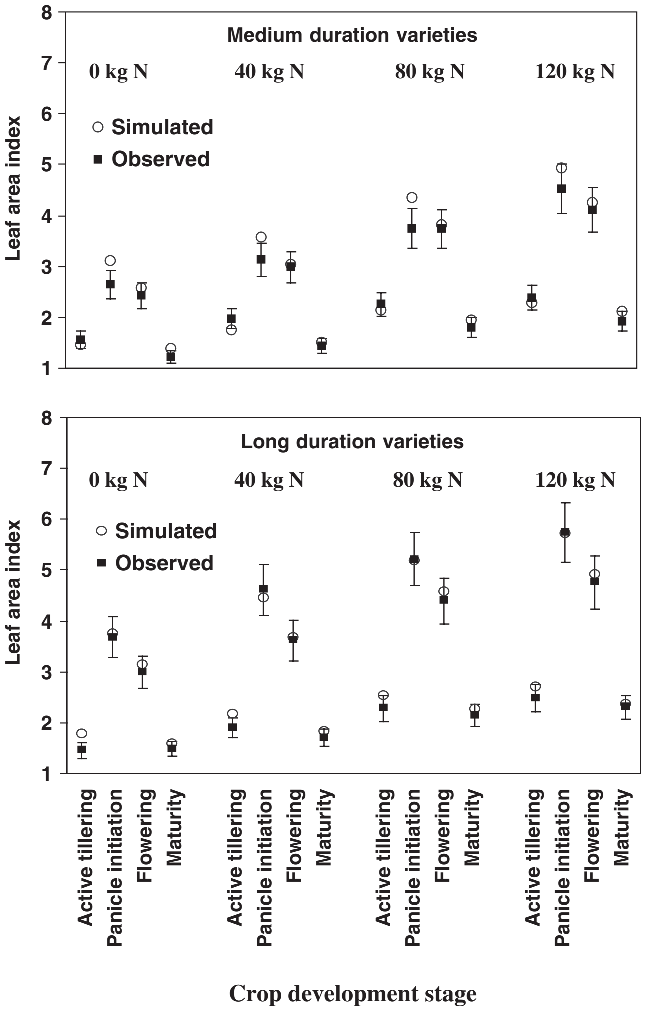

Fig. 4. Comparison between observed and simulated leaf area index at all development stages of medium- and long-duration rice varieties grown with 0, 40, 80, and 120 kg N ha^{-1} at Cuttack, India during the wet season of 2001 for ORYZA 1N model calibration. Vertical lines indicate SD.

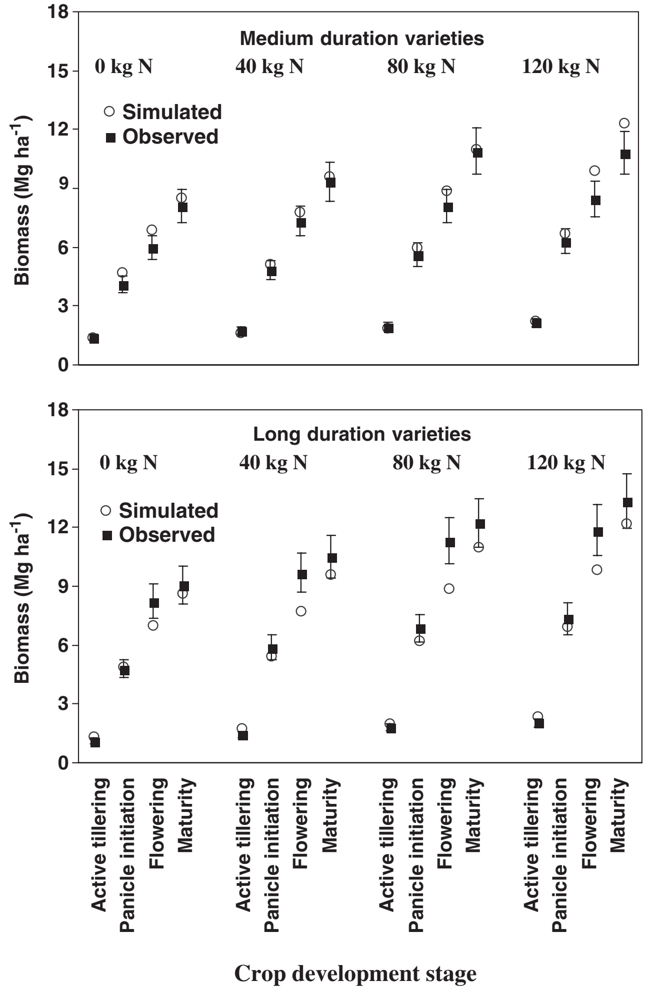

Fig. 5. Comparison between observed and simulated biomass at all development stages of medium- and long-duration rice varieties grown with 0, 40, 80, and 120 kg N ha^{-1} at Cuttack, India during the wet season of 2001 for ORYZA 1N model calibration. Vertical lines indicate SD.

thesis as influenced by genotypes of different duration and morphology.

Maintenance respiration consumes 15 to 30% carbohydrate produced by the crop (Penning de Vries et al., 1989). The model accounts for this by assuming it will be proportional to the fraction of accumulated leaf weight that is still green (Spitters et al., 1989). During the wet season, Swain et al. (2000) found significant differences in the net photosynthetic rate and maintenance respiration rate of two medium-duration rice varieties that were of similar duration but different height. The net photosynthetic rate of the tall variety Swarnaprabha (125 d maturity) was greater than that of the semidwarf variety Ratna (120 d maturity) at all growth stages. The maintenance respiration rate of Swarnaprabha was slower than Ratna during maximum tillering and panicle initiation but faster at flowering and 15 d after flowering. Baker et al. (1992) reported that the canopy dark respiration rate of rice reached maximum 30 to 50 d after planting, followed by a gradual decline with time until the end of the growing season, similar to photosynthesis (Baker et al., 1990). Such studies need to be extended for rice varieties of varying durations and morphology. The accurate quantification of these processes for groups of rice varieties in relation to development stages is needed to improve the ORYZA 1N model.

The extinction coefficient of sunlight (k) from Beer's law (Monsi and Saeki, 1953) ranges from 0.4 for erect leaves to about 0.8 for droopy leaves (Yoshida, 1981). The N profile in the canopy correlated with extinction coefficient, following an exponential pattern. In the model, this is accounted for by using an extinction coefficient specified for each development stage. The extinction coefficient value of 0.4 was based on preliminary measurements in field experiments at the IRRI, Philippines during grain filling (Kropff et al., 1994). Similar mean k values of 0.34 to 0.45 were derived for four rice cultivars in the USA (Kiniry et al., 2001). The long-duration varieties have higher LAI than medium-duration varieties from panicle initiation to flowering. Crops with a high LAI have the tendency to lodge, which decreases growth rate and flowering. Thus, there is a considerable scope for the improvement of the model for its wide application to long-duration genotypes differing in height and morphology.

The results (Fig. 6) of our study at 80 kg N ha^{-1} during the wet season of 2000 indicate that ORYZA 1N can accurately predict the performance of these 12 varieties on rainfed lowland soils that are not suffering from water stress. The model explained more than 90% of the variation in observed data on biomass and yield of medium- and long-duration varieties pooled together.

Ranking of Genotypes

The close proximity of simulated and observed rice yields reported in a study by Palanisamy et al. (1995) demonstrated how a simulation model can increase the efficiency of identifying the best genotypes at multi-location trials. Our results (Table 3) were similar to those of Palanisamy et al. (1995). Our paired *t* test indicated no significant differences between the observed and simulated yield of the 12 varieties studied at all rates of N application. The R^2 ranged from 0.86 to 0.90.

The observed mean grain yield of medium-duration varieties was 3.77 Mg ha^{-1} at native soil fertility level (0 kg N ha^{-1}), which increased to 4.82 Mg ha^{-1} at 80 kg N ha^{-1} application, and no significant difference in yield was noted among the varieties. Simulated mean grain yield of medium-duration varieties was 3.56 Mg ha^{-1} at native soil fertility level, which increased to 4.60 Mg ha^{-1} with N application at 80 kg N ha^{-1}. The simulated grain yield of Mahamaya and IR 36 were higher than the rest of the medium-duration varieties.

The observed and simulated mean grain yield of long-duration varieties increased with increasing N application rate up to 80 kg N ha^{-1}, beyond which there was marginal rise. At 80 kg N ha^{-1}, the observed and simulated grain yield of Ranjit and Savitri were significantly higher than that of other long-duration varieties. The lower grain yield of Mahsuri and Madhuri could be associated with their tendency for lodging.

The response of N application to observed grain yield was up to 80 kg N ha^{-1} for all varieties except for Savitri and Swarna. Under these conditions, the optimum amount to apply would be 80 kg N ha^{-1}. De Datta and Malabuyoc (1976) reported that the response of N during the wet season in the tropics was up to the application level 80 to 90 kg N ha^{-1}. Further, N application up to 120 kg N ha^{-1} reduced grain yields of several rice varieties. At the crop's maturity, we also observed a high N concentration in leaf (range 0.6–1.2% N; mean 0.8%), stem (range 0.5–0.8%; mean 0.7%), and grain (range 1.1–1.9% N; mean 1.4% N) at the highest N application rate, which could be related to the reduction in yield that we observed. The yield reduction could be due to reduced plant N use efficiency for grain pro-

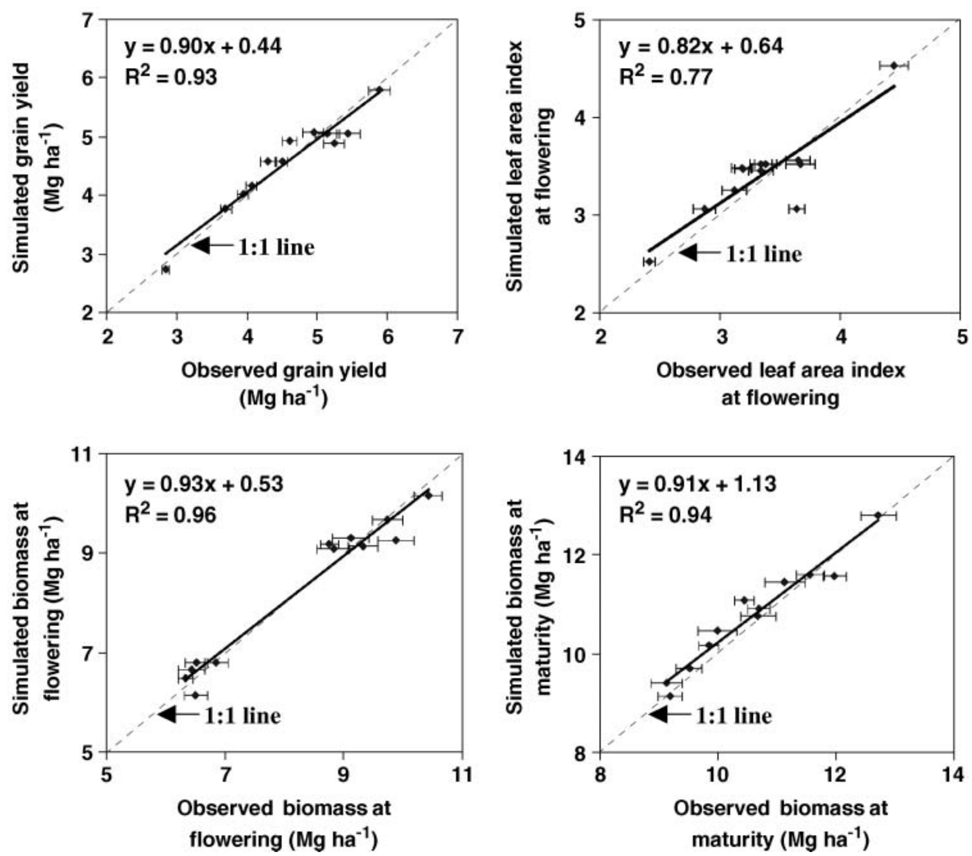

Fig. 6. Agreement between observed and simulated grain yield, biomass at flowering and maturity, and leaf area index at flowering of medium- and long-duration rice varieties grown with 80 kg N ha^{-1} at Cuttack, India during the wet season of 2000 for ORYZA 1N model verification. Horizontal lines indicate SD.

Table 3. For the most part, the ORYZA 1N model accurately predicted the performance of the actual rice crop grown at four N application rates (0, 40, 80, and 120 kg ha^{-1}) during the wet season of 2001 at the Central Rice Research Institute, Cuttack, India.

	N application rates†							
	N_0		N_{40}		N_{80}		N_{120}	
Varieties	Observed	Simulated	Observed	Simulated	Observed	Simulated	Observed	Simulated
	grain yield, Mg ha^{-1}							
	Medium-duration							
IR 36	3.68ab‡	3.85a	4.36ab	4.53a	4.93a (1)	4.99a (1)	4.75ab	5.22a
Mahamaya	4.11a	3.86a	4.51a	4.14ab	5.04a (1)	4.87a (1)	5.26a	5.17a
Kranti	3.63ab	3.45ab	3.89b	3.95bc	4.59a (1)	4.66a (1)	4.16c	4.90a
Lalat	3.98ab	3.03b	4.49a	3.43c	4.89a (1)	3.83b (2)	4.94a	4.04b
Khitish	3.45b	3.62a	3.90b	3.83bc	4.65a (1)	4.67a (1)	4.28bc	5.06a
Mean	3.77	3.56	4.23	3.97	4.82	4.60	4.67	4.87
	Long-duration							
Mahsuri	1.98cd	2.23c	2.63d	2.72d	3.22d (4)	3.05d (4)	3.43d	3.22d
Madhuri	1.71d	1.64d	1.98e	2.12e	2.88d (4)	2.85d (4)	2.91e	3.09d
Savitri	4.50a	4.85a	5.51a	5.26b	6.24a (1)	6.09a (1)	6.93a	6.92a
Rajsree	2.36bc	2.51bc	2.86cd	3.25d	3.85c (3)	4.16c (3)	3.92d	4.38c
Swarna	2.89b	2.93b	3.99b	4.10c	5.12b (2)	5.16b (2)	5.81c	5.96b
Sashi	2.63b	2.51bc	3.27c	3.02d	3.77c (3)	3.75c (3)	3.58d	3.98c
Ranjit	4.46a	4.46a	5.63a	5.82a	6.27a (1)	6.35a (1)	6.37b	6.59a
Mean	2.93	3.02	3.69	3.76	4.48	4.48	4.71	4.88
Paired *t* test ($n = 12$)	not significant		not significant		not significant		not significant	
R^2	0.87		0.88		0.90		0.86	

† Figures in parentheses indicate rank position of varieties.
‡ In a column, means followed by a common letter are not significantly different at the 0.05 level by Duncan's Multiple Range Test.

duction at high N concentrations in the leaf, stem, and grain. Shi and Akita (1993) concluded that large N uptake with application rates beyond 80 kg N ha^{-1} could cause a high LAI, which they say could enhance carbohydrate losses via dark respiration and therefore could limit additional grain production. Instead of merely pouring on additional amounts of costly N to boost rice yields, Tirol-Padre et al. (1996) sought to improve efficiency of uptake and use of existing N in the soil. They identified low stem N concentration for yield improvement.

The performance of rice has been known to degrade at higher N levels. Yoshida and Parao (1976) reported lower filled-spikelet percentage, and Ishizuka (1971) found increasing sterility. High N concentrations also have been known to increase lodging in taller varieties and to cause greater instances of pests and diseases. Wet seasons have increased cloudiness and decreased solar radiation during grain filling and ripening, which cause lower yields than in dry seasons. The model does not take any of these problems into account and instead continues to show a yield increase with increasing N rates up to 120 kg ha^{-1}. However, the model identified optimum N application rate from the response of simulated yield to N application. The observed and simulated grain yield response to N application was steep up to 80 kg N ha^{-1} for medium- and long-duration varieties in the wet season. The increase in simulated grain yield from applied N beyond 80 kg N ha^{-1} to medium- and long-duration varieties is 6.75 kg and 10 kg per each kg N, respectively, which are 45 to 50% lower than the response up to 80 kg N ha^{-1}. On the basis of chances for lodging, sterility, and incidence of pests and diseases, the optimum rate of N application for the wet season can be identified as 80 kg N ha^{-1}.

The performance of medium- and long-duration varieties in the wet season of 2001 at 80 kg N ha^{-1} (Table 3) was considered for final ranking of simulated and observed grain yield. For the long-duration varieties, Ranjit and Savitri were in top position, followed by Swarna. The grain yield of the top-ranking long-duration varieties was around 1.4 Mg ha^{-1} greater than that of the top-ranking medium-duration varieties (Mahamaya/IR 36) at all N levels. Savitri has a short, thick grain, but Ranjit has a superior fine grain with better market value. Thus, we recommended Ranjit variety at 80 kg N ha^{-1} for farmers' fields.

Extrapolation of Findings to Other Environments

Trends shown by crop-simulated yields are usually more reliable than their absolute values because these models are sometimes too sensitive to biological parameters but generally respond properly to weather fluctuations (Palanisamy et al., 1993). After we had verified the ORYZA 1N model, we used it to estimate the relative performance of several varieties during the wet seasons of three separate years under a variety of planting dates and N application levels (Table 4) at the experimental site that experienced hot and humid climate. The weekly mean maximum temperature ranges from 27.2°C (±0.3°C) in January to 37.6°C (±0.4°C) in May, and the weekly mean minimum temperature ranges from 13.7°C (±0.3°C) in December to 26.6°C (±0.2°C) in May. The annual rainfall average is 1536 mm (±80 mm). The crops growth was simulated under varying weather conditions when planted in an interval of 15 d between 15 July and 15 August. Based on the optimum response of N application to grain yield, the variety-specific input parameters derived at 80 kg N ha^{-1} from the field experiment of 2001 were used for all N levels. The simulated mean grain yield of Ranjit was highest of all the varieties at each N level and planting date. The best yields were obtained with a 15 July planting and declined steadily for all dates and varieties after that. Yield

Table 4. When the ORYZA 1N model was used to simulate the effect of planting dates on rice grain yield (averaged over 1997, 1998, and 1999), that accurately predicted the decline in yield if planted late in the wet season in India.

	Planting dates											
	15 July				31 July				15 Aug.			
Varieties	N_0	N_{40}	N_{80}	N_{120}	N_0	N_{40}	N_{80}	N_{120}	N_0	N_{40}	N_{80}	N_{120}
	grain yield, Mg ha^{-1}											
	Medium-duration											
IR-36	4.89	4.97	5.04	5.11	4.75	4.82	4.89	4.96	3.41	3.46	3.51	3.56
Mahamaya	4.88	4.96	5.03	5.10	4.42	4.49	4.56	4.62	3.37	3.42	3.47	3.52
Kranti	3.88	3.94	4.00	4.05	3.81	3.88	3.93	3.99	3.07	3.12	3.16	3.21
Lalat	4.10	4.17	4.23	4.29	3.80	3.86	3.91	3.97	2.75	2.79	2.83	2.87
Khitish	4.60	4.68	4.75	4.81	4.26	4.33	4.39	4.45	3.21	3.26	3.30	3.35
	Long-duration											
Mahsuri	4.42	4.49	4.55	4.61	3.48	3.53	3.58	3.63	2.73	2.78	2.82	2.85
Madhuri	3.12	3.17	3.22	3.26	3.19	3.24	3.29	3.34	2.49	2.53	2.57	2.60
Savitri	4.83	4.91	4.98	5.05	4.23	4.29	4.36	4.42	3.40	3.46	3.51	3.55
Rajshree	4.71	4.79	4.86	4.93	3.65	3.71	3.76	3.81	2.84	2.89	2.93	2.97
Swarna	4.75	4.83	4.90	4.97	4.18	4.25	4.31	4.37	3.23	3.28	3.33	3.38
Sashi	4.42	4.49	4.55	4.61	4.14	4.21	4.27	4.33	3.22	3.27	3.32	3.36
Ranjit	5.51	5.59	5.68	5.75	4.71	4.78	4.85	4.92	3.61	3.67	3.72	3.77
Mean	4.51	4.58	4.65	4.71	4.05	4.12	4.18	4.23	3.11	3.16	3.21	3.25

declines were around 10% at all N levels with a 15-d delay in planting (to 30 July) and up to 31% with an additional 15-d delay in planting (to 15 August). The recommended date of planting was around 15 July for the wet season rice. Farmers were advised to complete nursery sowing within 15 to 20 June to facilitate transplanting by the recommended date. Chandra and Manna (1989) and Pandey et al. (2001) also found 15 to 31 July as the optimum time for transplanting of 30-d-old seedlings, beyond which there was severe reduction in grain yield. On the basis of simulated grain yield for 3 yr under possible planting dates, variety Ranjit was recommended for the farmers' field.

The grain yield response to increased N application from 0 to 120 kg ha^{-1} seemed to be very low. It was due to input of single value of the N fraction in leaves at 80 kg N ha^{-1} to the model. The greatest simulated grain yield response was at 80 kg N ha^{-1}, after which it declined, confirming the recommendation for an application level of 80 kg N ha^{-1}.

The best new technology from the simulation studies was variety Ranjit at N application rate 80 kg ha^{-1}. The normal N application timing of four equal splits at basal, active tillering, panicle initiation, and flowering, which is usually recommended for the farmers by the state department of agriculture, was added to the new technology because ORYZA 1N did not identify the timing of split N application. However, the yield response to different timings is complex, and crops fertilized at different timings may increase yield in different ways (Cook and Evan, 1983). It is possible to generate a site-tailored recommendation for the number of split doses and their timings of any N application level to irrigated rice by the help of ORYZA_0 (MANAGE-N) submodel (ten Berge et al., 1994). The MANAGE-N identifies the best N fertilizer application schedule for maximum grain yield when a total amount of user-defined N input and a number of varietal and environment characteristics are provided (ten Berge et al., 1997a, 1997b).

We compared the structure of new technology (variety Ranjit fertilized with 80 kg N ha^{-1} in four equal splits) with existing farmer's practice (variety Swarna fertilized with 40 kg N ha^{-1} in two equal splits at basal and panicle initiation). Farmers said they use fewer applications of less N because they had not found additional return from their investments in higher N rates or splits.

Impact of New Technology

The combined ANOVA for biomass, yield, and yield attributes indicates that the effects of variety, N rate, and N splits were independently significant for biomass productivity (Table 5). The main effect of all the test factors or their interactions did not contribute for any significant effect on panicle m^{-2}, thousand-grain weight, and harvest index. However, the number of fertile grains per panicle was significantly influenced by variety alone. The sterility was not influenced by N splits but by variety and N level. The effect of variety alone was not sig-

Table 5. Combined ANOVA that showed the significance of recommended variety, N rate, and N splits and their interactions on biomass, grains per panicle, sterility, and grain yield in the technology verification trial conducted in the farmers' fields at the village Kasiadihi, Dhenkanal district, India, during the wet season of 2002.

		Sum of squares			
Source of variation	df	Total biomass at maturity	Grains per panicle	Sterility	Grain yield
Treatment	7	40.85*	4406.88*	122.88**	4.39**
Variety (V)	1	25.54**	3655.13**	60.50**	0.21 NS
N rate (L)	1	5.39*	450.00 NS	32.00**	2.07**
N splits (T)	1	9.21*	105.13 NS	6.13 NS	0.47*
V × L	1	0.15 NS†	0.50 NS	1.13 NS	1.14**
V × T	1	0.36 NS	171.13 NS	2.00 NS	0.07 NS
L × T	1	0.13 NS	12.50 NS	18.00*	0.002 NS
V × L × T	1	0.06 NS	12.50 NS	3.13 NS	0.42*

* Statistically significant at $P = 0.05$.
** Statistically significant at $P = 0.01$.
† NS, not significant.

Table 6. The significant effect of recommended variety, N rate, and N splits and their interactions on biomass, yield components, and grain yield in the technology verification trial conducted in the farmers' fields at the village Kasiadihi, Dhenkanal district, India, during the wet season of 2002.†

Treatment	Total biomass	Panicles m^{-2}	Grains per panicle	Thousand grain weight	Harvest index	Sterility	Grain yield
	Mg ha^{-1}			g		%	Mg ha^{-1}
RV + RL + RT	12.25	272.00	118	17.18	0.48	14.5	5.51
RV + RL + FT	11.00	265.00	107	17.13	0.47	12.8	5.11
RV + FL + RT	11.33	253.00	111	17.90	0.45	14.8	4.37
RV + FL + FT	10.00	245.50	106	17.20	0.44	17.3	4.47
FV + RL + RT	10.02	246.00	89	18.68	0.51	16.5	4.83
FV + RL + FT	9.37	258.50	92	18.15	0.52	17.0	4.71
FV + FL + RT	9.55	271.50	83	18.43	0.48	17.3	4.91
FV + FL + FT	8.48	248.50	99	18.15	0.49	19.5	4.36
LSD (P = 0.05)							
Variety (V)	1.10	NS	15	NS	NS	1.5	NS
N rate (L)	1.10	NS	NS	NS	NS	1.5	0.29
N split/timings (T)	1.10	NS	NS	NS	NS	NS	0.29
V × L	NS	NS	NS	NS	NS	NS	0.41
V × T	NS	NS	NS	NS	NS	NS	NS
L × T	NS	NS	NS	NS	NS	2.1	NS
V × L × T	NS	NS	NS	NS	NS	NS	0.58

† FL, farmer's N rate; FT, farmer's splits/timing of N application; FV, farmer's variety; NS, not significant; RL, recommended N rate; RT, recommended splits/timings of N application; RV, recommended variety.

nificant for grain yield production; rather, the effect of N rate or N splits was significant. The interaction of variety and N rate was highly significant.

Farmer's practices produced minimum biomass and grain yield, whereas the new technology produced the maximum of both (Table 6). The fertile grain per panicle was higher in new technology as compared with farmer's practice, whereas the thousand-grain weight and harvest index were comparable. The most important contributor to gains in biomass was the improved variety, followed by the increase in N amount (Table 7). Additional splits in the N applications decreased biomass. The gain in grains per panicle was mostly contributed to by the improved variety only. The reduction of grain sterility in new technology as compared with farmer's practice was due to improved variety. The gain in grain yield by new technology over farmer's practice was largely attributed to improved variety with higher N rate.

CONCLUSIONS

The crop growth simulation model ORYZA 1N can replace the need for years of costly multilocation, on-station, and on-farm trials to select rice varieties. The output of the simulation recommended a new rice variety, Ranjit, for adoption by the farmers in nonwaterstressed rainfed lowlands with a N application level of 80 kg N ha^{-1}. Technology verification trials of this practice produced 5.51 Mg ha^{-1} of rice, compared with 4.36 Mg ha^{-1} grown with the conventional practices of area farmers. The yield gain of 0.65 Mg ha^{-1} was accounted for mainly by adoption of the model-recommended variety that was most responsive to higher rate of N application. The highest grain yield could be obtained with rice planted near 15 July in the wet season. There is ample scope for application of the calibrated model to identify better cultivars and management practices for irrigated rice grown in dry season or for rainfed lowland rice in wet season without any water stress.

Table 7. Average mean contribution of recommended variety, N rates, and N splits to the difference between new technology and farmer's practice in biomass, grain yield, sterility, and grains per panicle at the technology verification trial conducted in the farmers' fields at the village Kasiadihi, Dhenkanal district, India, during the wet season of 2002.

Test factors	Total biomass	Grains per panicle	Sterility	Grain yield
	Mg ha^{-1}		%	Mg ha^{-1}
Variety (V)	3.60**	21**	−2.56**	0.12 NS
N rate (L)	0.42*	3.2 NS†	−1.14**	0.35**
N splits (T)	−1.06*	0.5 NS	−1.00 NS	0.55*
V × T	–	–	–	0.35 NS
V × L	–	–	–	0.50**
L × T	–	–	–	0.39 NS
V × L × T	–	–	–	0.83*
Avg. gap (13 farms)	2.96	25	−4.7	0.65

* Statistical significance at P = 0.05.
** Statistical significance at P = 0.01.
† NS, not significant.

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