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Impact of climate change scenario on rice production in two planting methods: a simulation study

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Abstract In the present study, attempts have been made to simulate the effect of climate change on rice growth and yield, under both control and water-stressed conditions. Between the two planting methods, the system of rice intensification (SRI) practice had an advantage for the elevated CO_2 conditions, with an additional yield of 1,325 kg ha^{-1}; while it was only 391 kg ha^{-1} under traditional system of planting rice (TPR). Similarly, the yield decline due to temperature increment was −2.0, −2.4, −6.2 and −12.8 % under SRI practice as compared to that of −4.0, −9.9, −11.3 and −31.7 % in the TPR system for +1, +2, +3 and +4 °C temperature rise, respectively. Thus, doubling of atmospheric CO_2 level will compensate for the detrimental effect of increased temperature up to 2 °C in the SRI method of rice cultivation as compared to TPR system of planting. Thus, SRI practice is the most suitable method of rice cultivation under both elevated CO_2 and temperature level. Simulation analysis of the present data using the dynamic model, ORYZA2000, indicated that under future adverse climatic conditions, the grain yield showed little variation (+1.83 %) with doubled CO_2 at +2 °C temperature rise especially with the water stress situations. However, this could be further raised (+17.10 %) with the supplementation of pink-pigmented facultative methylotroph bacterium (PPFM) bio-fertilizer in the given scenario. Thus, temperature-induced yield alterations especially under water-stressed environment could be favorably mitigated with the CO_2 fertilization along with the supplementation of PPFM bio-fertilizer.

Keywords Crop modeling · Elevated carbon dioxide · ORYZA2000 · System of rice intensification · Temperature · Water stress

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Introduction

Water-deficit environment is one of the most serious factors limiting production and productivity of rice, especially under transplanted lowland ecosystem. Further, lowland rice fields have relatively high water requirements, and their sustainability is threatened by increasing water scarcity (Bouman et al. 2001). Thus, there is an urgent need to develop water-saving irrigation strategies, and a new method of cultivation must be identified to seek higher productivity. System of rice intensification (SRI), a new approach, is one such practice which helps to economize the irrigation water. SRI technique was first developed at Madagascar about 20 years ago by Fr. Henri de Laulanine, S.J. along with the farmers. Yield with the SRI has been typically around 8 t ha^{-1}, whereas the national average was only 2 t ha^{-1} (Hirch 2000). The most widely promoted water-saving technology in SRI is alternate wetting and drying (AWD); instead of keeping the fields always under submerged condition, the soil is allowed to dry-out for a few days after disappearance of the irrigated water, before it is flooded again. Recent results indicated that under SRI method of cultivation, about 42 and 50 % of irrigation water could be saved over the integrated crop management and conventional method, respectively (Annie Poonam and Rao 2007), which ultimately reduced the cost of production to half, over the conventional cultivation.

Rice growth and yield under optimal conditions are largely determined by weather during the growing season. Carbon dioxide concentration in the atmosphere had increased considerably since pre-industrial times with current mean annual increment of about 1.5 ppm (Keeling et al. 1984). According to the current model predictions, the increase in CO_2 and other greenhouse gases was likely to rise the earth's temperature over the next 50 years, with concurrent changes in precipitation patterns. Climate change, via increasing atmospheric CO_2 concentration, can affect global agricultural production by affecting photosynthesis (Cure and Acock 1986) and transpiration rates (Sionit et al. 1980). Increase in temperature speedup the plant development and alternatively decreases the duration of the grain-filling period (Stansel and Fries 1980). Thus, an increase in the daily mean temperature might reduce the crop yield potential in many areas. The combined effects of elevated CO_2 with increasing temperature on the crop growth and productivity were partly unknown and were currently under investigation.

Field experimentation and simulation modeling are a powerful combination to understand complex crop–water interactions and to extrapolate site-specific empirical results to other environments and conditions. The rice growth model ORYZA2000 has been used to quantify trade-offs between yield and water usage and to distinguish between "real" water savings in depletion flows and to extrapolate empirical results in relation to different weather and hydrological conditions (Feng et al. 2007). Bouman et al. (2007) used ORYZA2000 to extrapolate the experimental results to other years and hydrological conditions and explored options to reduce water inputs and depletion flows for maintaining higher yields in rice.

Effect of various treatment combinations on growth and yield of a given variety to varied atmospheric locations are possible through simulation models. Further, models are the best tools to synthesize current knowledge and hypotheses to estimate directional trends for potential changes in rice yield due to climate change. In this article, we present the findings of the field experiments and parameterization and evaluation of ORYZA2000 model according to the future climate change scenario.

The present study was conducted in the Tamil Nadu Agricultural University (TNAU), Coimbatore, India, during wet and dry Season of 2006–2007 using the rice varieties CO 43 (135–140 days) and ADT 43 (115–120 days), respectively.

Materials and methods

Field experiment

The field experiments were conducted in the TNAU, Coimbatore, India, during wet and dry Season of 2006–2007 using the rice varieties CO 43 (135–140 days) and ADT 43 (115–120 days), respectively. The experiments were conducted on clay-loam soil in low-land rice area at wet land, Central Farm of TNAU (11°N, 77°E; 426.72 m altitude). In the present study, both SRI and TPR methods of rice cultivation were practiced. In TPR, 20-day-old seedlings were transplanted at a spacing of 20 cm × 10 cm and 15 cm × 10 cm during both wet and dry season, respectively. In SRI, 14-day-old seedlings were transplanted at 25 cm × 25 cm spacing in both the season. The experiments were laid out in a split plot design, replicated thrice with water management practices as the main plot treatments and mitigation practices in the sub-plot treatments. Size of the each plot was measured 4 m × 5 m. The experimental plots were laid out with double channels (buffer channels) around all the plots to prevent sub-soil lateral water flow. The main plot includes: "SRI" planting + recommended irrigation schedule (M_1), "SRI" planting + modified irrigation schedule (M_2), TPR planting + recommended irrigation schedule (M_3) and TPR planting + modified irrigation schedule (M_4). For the SRI and TPR method of planting, the recommended irrigation plots were irrigated up to 2 and 5 cm depth 1 day after disappearance of irrigated water, respectively. In the former case, this was pursued up to flowering. Thereafter, irrigation was given to 5 cm depth until 7 days before harvest.

For the modified irrigation schedule M_2 and M_4 plots, the water stress was imposed in two phases, viz. first one during panicle initiation (60–80 days after sowing (DAS) for CO 43 during wet season (WS) and 50–65 DAS for ADT 43 variety during dry season (DS) and second one during flowering stage (95–115 DAS for WS and 80–95 DAS for DS) by with-holding irrigation at the specified stages for both seasons. The stress was imposed 1 day after disappearance of irrigated water, during panicle initiation and flowering stage. Whenever rain fall was received during the stress period, the rain water was immediately drained off from the respective plots without allowing the rain water to percolate down the soil.

After the termination of the stress period, the stressed plots were re-irrigated to the required depth immediately in both SRI and TPR methods of planting, during both seasons as specified above. In both non-stressed and stressed plots, irrigation was suspended 7 days before the expected time of harvest.

The sub-plot treatments, viz. control (S_1), 0.5 ppm brassinolide (BR; S_2), 100 ppm salicylic acid (SA; S_3), 1 % Potassium chloride (KCl; S_4) and spray of pink-pigmented facultative methylotroph (PPFM; S_5) bacterial isolate load of 10^6 at 1 ml l^{-1} were imposed at both panicle initiation and flowering stages 1 day after imposing the stress. Plant samples were drawn at the chosen stages for recording various morphological and physiological parameters by adopting standard procedure (Yoshida et al. 1971).

Crop simulation modeling

Model description

For the present study, an eco-physiological model, ORYZA2000, is used that simulates the growth, development and water balance of rice in situations of potential production and water limitations with time steps of 1 day (Bouman et al. 2001). It is assumed that the crop is well protected against diseases, pests and weeds. A detailed description of the model is given by Bouman et al. (2001) and a brief description of the model is given below.

In the ORYZA2000 model, crop phenology, leaf area index (LAI), partitioning of dry matter and quantity of water applied during the crop period were taken as the forcing functions. Water stress effects on leaf expansion, leaf rolling, leaf senescence and photosynthesis, assimilate partitioning, root growth and spikelet sterility were calculated as a function of the soil water tension in the root zone, using the module PADDY for computing the soil water dynamics of the puddle lowland soils (Wopereis et al. 1996; Bouman et al. 2001). The water retention and conductivity characteristics are expressed by Van Genuchten parameters (Van Genuchten 1980).

Model parameterization

The model ORYZA2000 was parameterized following the procedure of Bouman and Van Laar (2006). The crop and water applied data for $M_1 \times S_1$, $M_1 \times S_5$, $M_2 \times S_1$, $M_2 \times S_5$, $M_3 \times S_1$, $M_3 \times S_5$, $M_4 \times S_1$ and $M_4 \times S_5$ treatments for WS (CO 43) and DS (ADT 43) were used for parameterization of the model. Development rates were calculated using the recorded dates of sowing, transplanting, panicle initiation, flowering and maturity in each treatment. In the case of non-stressed control treatments, the model ORYZA2000 was run for the potential production situation. Data on LAI and partitioning of dry matter among leaf, Culm, root and panicles, used as forcing functions in the model, were taken for the above treatments and parameterized in the model. In the case of water-stressed treatments, the quantity of water applied was used as forcing function in addition to the data on other chosen parameters. In the present study, the water balance was computed using Penman's water balance equation for different treatments. Such quantification is essential for calculating the amount of water going into the atmosphere through evaporation and transpiration in the chosen treatments (Bouman et al. 2001). In the present study, water balance was computed using Penman's water balance equation for different treatments. Such quantification is essential for calculating the amount of water going into the atmosphere through evaporation and transpiration in the chosen treatments.

Model evaluation

The performance of ORYZA2000 was evaluated for the chosen treatments in both the seasons using the corresponding required weather data. The model was also used to extrapolate to the future climate change scenario of elevated atmospheric CO_2 (680 vppm) level and temperature increase (up to +4.0 °C). The results of simulated grain yield and seasonal water use are presented and discussed in Tables 1 and 2.

Results and discussion

Crop simulation modeling

Model validation

Simulated grain yield of the chosen treatments are furnished in Table 1 along with the observed grain yield.

The results indicated that there was a fair agreement (direct correlation may be used) between simulated and observed grain yields for DS (ADT 43), while the agreement showed wide variation for WS (CO 43). Similar results were observed by Srivastava et al. (2004) showing good agreement between observed and simulated grain yields in DS rather than WS. Therefore, further simulation runs, described in the following paragraphs, were made with special reference to DS for future climate change scenarios, based on the results of model validation.

Quantification of water flux

In the present simulation study, total water use, evaporation (EP) and transpiration (T) during DS have been quantified using ORYZA2000 model for irrigated rice ecosystem (Table 2). With the help of the model, the water flux has been quantified for the chosen treatments during DS (2007). Penman's water balance equations have been used in the model for this computation.

Table 1 Validation of grain yield (kg ha^{-1}) simulated by ORYZA2000 model in two different seasons using parameters of chosen treatments

Treatments	Wet season (CO 43)		Dry season (ADT 43)	
	Observed yield	Simulated yield	Observed yield	Simulated yield
$M_1 \times S_1$	6,081	↑8,580 (41.10 %)	6,219	↑6,983 (12.28 %)
$M_2 \times S_5$	7,019	↑9,971 (42.09 %)	6,923	↑7,904 (14.17 %)
$M_2 \times S_1$	4,990	↑5,404 (8.30 %)	5,114	↑5,541 (8.35 %)
$M_3 \times S_5$	6,109	↓5,923 (−3.04 %)	6,192	↑6,430 (3.84 %)
$M_3 \times S_1$	6,019	↑10,162 (68.83 %)	5,977	↑6,679 (11.74 %)
$M_4 \times S_5$	6,798	↑10,511 (54.62 %)	6,476	↑7,171 (10.73 %)
$M_4 \times S_1$	4,035	↑9,992 (147.63 %)	4,680	↑5,690 (21.56 %)
$M_1 \times S_5$	5,731	↑10,520 (85.56 %)	5,645	↑6,337 (12.26 %)

Figures in parentheses indicate % deviation from the observed yield estimates. Up-arrows (↑) indicate overestimation and down arrow (↓) indicates underestimation. M_1—SRI with conventional irrigation, M_2—SRI with stress at PI and FF, M_3—TPR with conventional irrigation, M_4—TPR with stress at PI and FF, S_1—control, S_5—10^6 PPFM bacterial isolate. In both cases, an estimate of <25 % represents good approximation of the reported yield (Srivastava et al. 2004)

Table 2 Values of observed and simulated total water used by ORYZA2000 for the chosen treatments, DS (2007)

Treatments	Observed total water use (mm)	Simulated total water use (mm)
$M_1 \times S_1$	620	↑640 (3.22 %)
$M_1 \times S_5$	620	↑640 (3.22 %)
$M_2 \times S_1$	470	↑486 (3.40 %)
$M_2 \times S_5$	470	↑486 (3.40 %)
$M_3 \times S_1$	1,070	↓1,050 (1.87 %)
$M_3 \times S_5$	1,070	↑1,100 (2.80 %)
$M_4 \times S_1$	820	↓700 (14.63 %)
$M_4 \times S_5$	820	↓700 (14.63 %)

Figures in parentheses indicate % deviation from the observed estimates. Up-arrows (↑) indicate overestimation and down arrow (↓) indicates underestimation. M_1—SRI with conventional irrigation, M_2—SRI with stress at PI and FF, M_3—TPR with conventional irrigation, M_4—TPR with stress at PI and FF, S_1—control, S_5—10^6 PPFM bacterial isolate. In both cases, an estimate of <25 % represents good approximation of the reported values (Srivastava et al. 2004)

The values for the chosen treatments indicated fairly a good agreement between observed and simulated ones, for the total water use, in both the planting systems for non-stressed as well as stressed treatments.

Scenario analysis: elevated CO_2 and temperature

Anthropogenic influences including rapid industrialization, urbanization, and combustion of fossil fuels, mining and deforestation have released enormous quantities of carbon dioxide (CO_2), methane (CH_4) and other "greenhouse" gases into the atmosphere. This in turn might have serious implications that lead to global warming with the consequent rise in earth's temperature (by 1–4 °C) which could have significant impact on the delicate balance of agricultural production systems that are so intricately associated with the weather system causing imbalance in food supply. Hence, it is imperative to study the effects of climate change on the yield of staple food crops such as rice. Objective of the following study was to understand the impacts of future climate on the rice production especially in relation to limited water supply situations.

The dynamic simulation model ORYZA2000 was evaluated under potential and N-limited conditions in the Philippines (Bouman and Van Laar 2006), under conditions of alternate wetting and drying AWD irrigation in China (Belder et al. 2007) and under N-limited and rainfed conditions in Indonesia (Boling et al. 2007). Different climate change scenarios (Matthews et al. 1995a, b, c) resulting from changes in temperature and atmospheric CO_2 concentrations were evaluated with ORYZA2000 model for their impacts on rice cultivation. Estimates were made to quantify the effect of CO_2 rise and temperature on the yield of rice grown in the DS of Coimbatore site. The details of different scenarios employed in the present simulation study are furnished below.

Scenarios used for both SRI and TPR systems of planting:

1. Current CO_2 340 vppm at +1, +2, +3 and +4 °C
2. Current CO_2 + stress at +1, +2, +3 and +4 °C
3. Current CO_2 + stress + PPFM at +1, +2, +3 and +4 °C
4. × 2 CO_2 680 vppm at +1, +2, +3 and +4 °C
5. × 2 CO_2 at + stress at +1, +2, +3 and +4 °C
6. × 2 CO_2 + stress + PPFM at +1, +2, +3 and +4 °C.

Table 3 Yield changes (kg ha^{-1}) predicted for SRI and TPR system of planting under two different scenarios of CO_2 and temperature increments

CO_2 level (vppm)	SRI planting					TPR planting					Overall mean
	+0 °C	+1 °C	+2 °C	+3 °C	+4 °C	+0 °C	+1 °C	+2 °C	+3 °C	+4 °C	
340	6,318	6,550	6,561	6,167	4,579	6,236	6,153	5,833	5,536	5,403	5,934
680	8,362	8,380	8,012	7,884	7,362	8,357	7,851	7,318	7,405	6,185	7,712

Effect of two varied levels of CO_2 and temperature by fixed increments were simulated using ORYZA2000 model. The simulation analysis was done using the daily weather data of Coimbatore Observatory. The dates of sowing and transplanting were selected as adopted in the field experiments during DS (2007). The results are presented in the Table 3.

Analysis of data from simulation studies indicates that there was a general increase in the grain yield with twofold rise of CO_2 level at all stage of temperature increment (Table 3). Between the planting methods, the SRI practice had an edge over the TPR system of planting. It was also inferred that the temperature-induced yield reduction, especially beyond +2 °C range, could be safely moderated with the elevated level of CO_2 in both the system of planting.

An increase in temperature reduces the grain yield in both the methods of planting, but the temperature effect was more drastic in TPR system than the SRI practice. For example, there was reduction in grain yield of SRI planting at +2 and +4 °C of temperature, and the reduction was only −2.4 and −12.8 %, respectively. However, with the same temperature increase, the reduction was −9.9 and −31.7 %, respectively, in the case of TPR system of planting (Table 4).

With respect to the water stress environment, the change in grain yield due to the stress was −20.3 and −19.8 % with 340 and 680 vppm, respectively. Thus, the water-stress-induced yield reduction was only marginal between current as well as increased CO_2 levels. Nevertheless, such reduction could be significantly narrowed down to −8.8 and 7.7 %, respectively, with the supplementation of PPFM bio-fertilizer for stress mitigation in the future climate change scenarios (Table 5).

Climate change is likely to have a significant impact on agricultural production depending upon the magnitude of temperature and CO_2 increase. The impact of global climate change on agriculture has been studied extensively for various crops at different scales (Lemon 1983; Acock and Allen 1985). However, relatively fewer studies have been focused on rice (Baker and Allen 1993; Horie 1993; Kropff et al. 1993; Mohandass et al. 1993; Penning de Vries 1993). An adverse effect of climate change on rice production had also been reported by Matthews et al. (1995a). Srivastava et al. (2004) analyzed the effects of

Table 4 Yield changes (%) predicted for SRI and TPR systems of planting under fixed temperature increments

Planting method	+0 °C	+1 °C	+2 °C	+3 °C	+4 °C
SRI	0	−2.0	−2.4	−6.2	−12.8
TPR	0	−4.0	−9.9	−11.3	−31.7

Table 5 Simulated changes in grain yield due to water stress and ameliorative treatments under two different CO_2 scenarios

Treatments	340 vppm CO_2 level		680 vppm CO_2 level	
	Grain yield (kg ha^{-1})	Change (%)	Grain yield (kg ha^{-1})	Change (%)
Control (no stress)	6,570	0.0	8,426	0.0
Water stressed	5,238	−20.3	6,758	−19.8
Stressed + PPFM	5,993	−8.8	7,776	−7.7

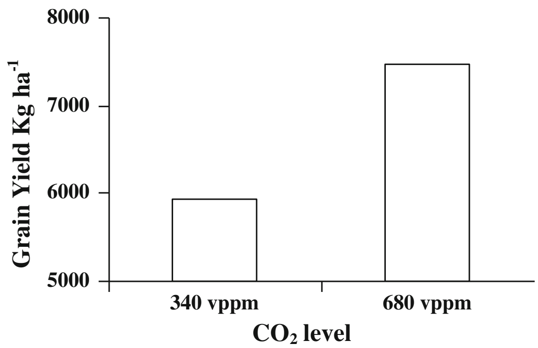

Fig. 1 Simulated grain yield under 340 and 680 vppm CO_2 levels

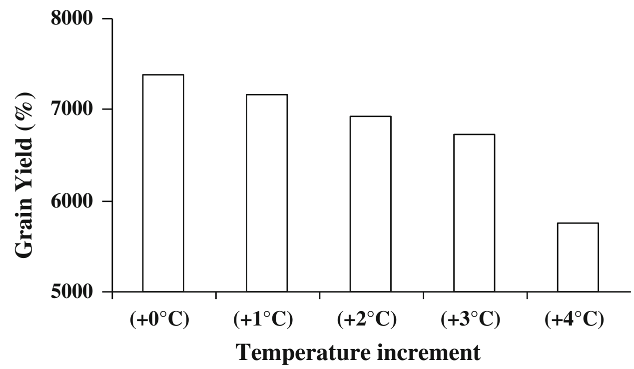

Fig. 2 Simulated grain yield with increment in temperature

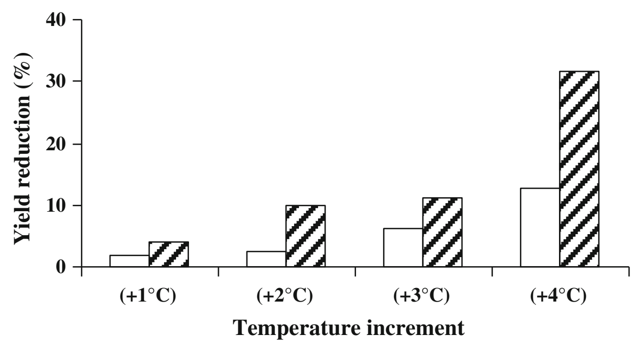

Fig. 3 Reduction in stimulated grain yield (%) due to temperature increase in two different planting methods

elevated temperature and CO_2 concentrations on the yield and water use of rice, grown in the three agro-ecologically different environments, to understand the possible impacts of climate change in rice based on agro-ecosystems. In the present study, an attempt has been made to simulate the climate change effects on rice production for both control and water-stressed situations. Simulation analysis indicated that there was a general increase in mean grain yield by 26.1 % with doubling of CO_2 than the current level (Fig. 1). On the contrary, the increment in temperature gradually reduced the yield by −3.0, −6.1, −8.7 and −22.1 % for +1, +2, +3 and +4 °C, respectively (Fig. 2).

Chamber experiment studies by Baker et al. (1990) showed increases in grain yield and biomass as CO_2 concentration increases together with an increase in canopy net photosynthesis and water use efficiency. Simulation studies conducted by Mohandass et al. (1995) indicated that the annual national rice production of India was likely to increase as CO_2 levels and temperature increase in future climates. Ranganathan and Mohandass (1997) suggested that altered crop phenology, early vigor, increased source size and its activity were found to be the efficient physiological traits for increasing yield plateau in the alleviation of temperature-induced detrimental effects of the future climate change scenarios.

Results from our studies indicate that between the two planting methods, the SRI practice had an advantage for the elevated CO_2 conditions, with an additional yield of 1,325 kg ha^{-1}; while it was only 391 kg ha^{-1} under TPR system of planting with the doubled CO_2 level. Similarly, the yield decline due to temperature increment was −2.0, −2.4, −6.2 and −12.8 % for the SRI practice and −4.0, −9.9, −11.3 and −31.7 % in the TPR system for +1, +2, +3 and +4 °C, respectively (Fig. 3).

In this content, doubling of atmospheric CO_2 level was sufficient enough to compensate for the detrimental effect of increased temperature up to 2 °C for the SRI practice, but it was not alike in the TPR system of planting. Therefore, from the present study, it is clear that the yield in the TPR system of planting would be much more affected by an increase in CO_2 level and the associated temperature increase as compared to that of the SRI practice (Fig. 4) in the future climates. Hence, in totality, it could be inferred that the SRI system of planting was better placed with regard to future climate change scenarios in terms of both elevated CO_2 and temperature levels. This difference reflected that the higher temperatures, normally encountered during DS, would affect the crop productivity by increasing the percentage of spikelet sterility, and this could be a major factor limiting the crop yield. This is especially true for the TPR system of planting in the present investigation.

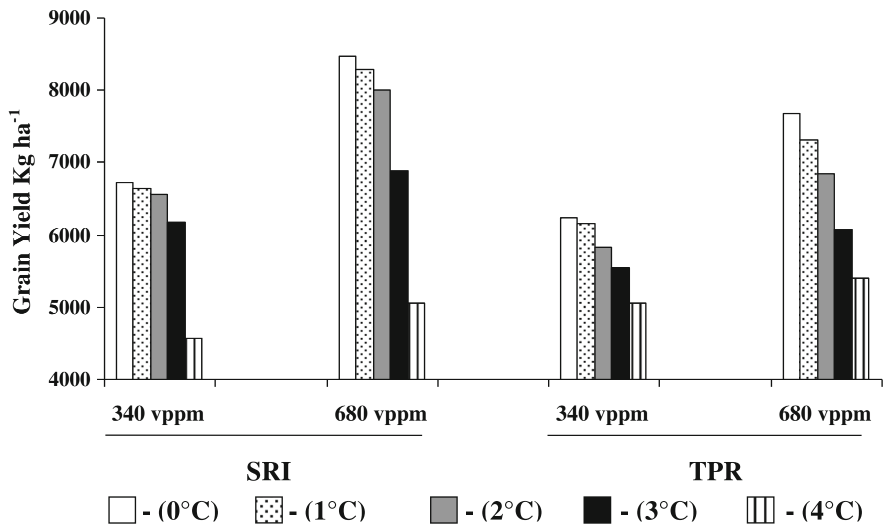

Fig. 4 Combined effects of CO_2 × temperature on grain yield in two planting methods

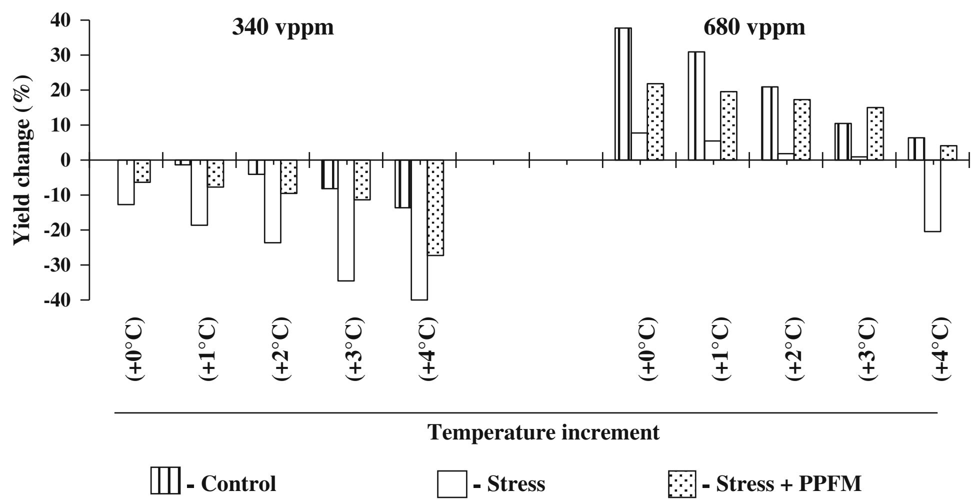

Fig. 5 Predicted grain yield changes (+ or −) in future climate change scenario in relation to current yield

In rice, spikelet fertility was influenced adversely by extreme temperatures immediately before and after flowering (Yoshida 1981). A reduction in spikelet fertility reduces the number of grains that could form, so that even if carbohydrate production in the grain-filling period was unaffected, yield was reduced (Matthews et al. 1995c). Similar reduction in spikelet fertility and modified crop duration due to temperature increase were observed by several authors (Kropff et al. 1994; Matthews et al. 1995b; Mohandass et al. 1995). Simulation analysis of combined effects of elevated CO_2 × temperature increase × water stress (Fig. 5) inferred that during the current climate of 340 vppm CO_2 concentration and normal environment, the mean decrease in grain yield with the temperature gradient +0, +1, +2, +3 °C and +4 °C were 6.5, 7.0, 11.5, 18.0 and 26.9 %, respectively. On the other hand, increasing the CO_2 level to 680 vppm (double), increases the yield by 22.4, 18.8, 12.2 and 11.6 % with the respective temperature increment of +0, +1, +2 and +3 °C, although a slight decrease by 1.9 % with +4 °C was observed.

However, the yield reduction due to water stress with current atmospheric CO_2 level (340 vppm) was −12.9, −18.6, −23.6, −34.6 and −39.8 % with the temperature increment of +0, +1, +2, +3 and +4 °C, respectively. Such reduction could be narrowed down to −6.6, −6.6, −9.5, −11.3 and −27.4 % at the temperature increment of +0, +1, +2, +3 and +4 °C, respectively, with the supplementation of PPFM bio-fertilizer in the stressed treatments. Thus, the role of PPFM for both water and temperature stress situations was phenomenal in alleviating the stress effects in future climate. Similarly, for doubling of atmospheric CO_2 concentration (680 vppm), the

Table 6 Range in values of transpiration and evaporation simulated by ORYZA2000 model during DS 2007

Treatments	Transpiration		Evaporation	
	(mm season^{-1})	Percent total water applied	(mm season^{-1})	Percent total water applied
SRI method				
Control	459.8	71.9	180.2	28.1
Stressed	310.5	63.9	175.5	36.1
TPR method				
Control	854.5	74.3	295.5	25.7
Stressed	772.8	67.2	377.2	32.8

predicted changes in the yield across temperature gradient with the stressed treatments were +7.8, +5.7, +1.8, −0.3 and −20.4 % with the temperature increment of +0, +1, +2, +3 and +4 °C, respectively. Possibility of increasing the yield under water stress situations was also evident with the supplementation of PPFM bio-fertilizer as noticed with the yield advantage by +21.7, +19.6, +17.1, +15.0 and −4.3 due to the temperature increment of +0, +1, +2, +3 and +4 °C, respectively.

Microorganisms that had the capacity to form intricate relationships with the plants produce significant quantities of plant growth regulators. Further, the bacteria removed metabolic waste products such as methanol from the apoplast of the host and using them as a nutritional source, degraded them into simple compounds, which were eventually returned to the plant (Holland 1997). The beneficial effects of PPFM on growth and development of crop plants had been attributed to the production of phytohormones (Holland 1997) and vitamin (Basile et al. 1985). While studying the potential of PPFM for cytokinin biosynthesis, Soumya (2005) revealed that the PPFM isolate produced trans-zeatin content and IAA production ranging from 22.04 to 117.32 ng g^{-1} and 0.14 to 4.69 µg ml^{-1} of culture filtrate, respectively. Thangamani (2005) reported that combined application of PPFM with 75 % N and P and 100 % K increased the growth and physiological parameters in terms of total chlorophyll, protein and phenol and also the activity of *Urease* enzyme in ADTRH 1 hybrid rice. Thus, through the simulation analysis, it can be presumed that the temperature-induced yield alterations in future climates especially under water-stressed environment could safely be narrowed down with the CO_2 fertilization along with the supplementation of PPFM bio-fertilizer.

Water flux

Close observation of the data (Table 6) on water flux as simulated by the ORYZA2000 model for the current climate during DS indicated that, under non-stressed conditions, the share of crop transpiration and soil evaporation in the SRI practice was found to be 71.9 and 28.1 %, respectively, for the total water applied. Similar results were observed by Srivastava et al. (2004).

However, for the stressed treatments, the shares were 63.9 and 36.1 % for transpiration and evaporation, respectively. Thus, the share of soil evaporation component was higher with the stressed treatments. Similar trend was observed for the TPR system of planting in both non-stressed and stressed scenarios with more shares for the transpiration component. Nevertheless, doubling of CO_2 and temperature increment in future climates showed very little alterations for the values of soil evaporation and crop transpiration (data not shown) components.

Conclusion

A model study is needed to disentangle the interacting effects of rainfall, irrigation, soil type and groundwater depth on the performance of the water-saving technology, AWD. ORYZA2000 was sufficiently accurate in the simulation of crop growth and soil water dynamics under flooded lowland conditions at our test site for such a purpose. Based on the simulation analysis, it is found that the temperature-induced yield alterations in future climates especially under water-stressed environment could be favorably mitigated with the CO_2 fertilization along with the supplementation of PPFM bio-fertilizer. Besides, the present investigation of simulation analysis had also paved a way for future research, taking into consideration that the identification of temperature-tolerant isolates of PPFM would prove to be much more beneficial in further raising the yield plateau as observed at the temperature increment of beyond +2 °C level in the future climates.

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