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Short communication

Field experiments and simulation to evaluate rice cultivar adaptation to elevated carbon dioxide and temperature in sub-tropical India

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ABSTRACT

Location specific adaptation option is required to minimize adverse impact of climate change on rice production. In the present investigation, we calibrated genotype coefficients of four cultivars in the CERES-Rice model for simulation of rice yield under elevated CO_2 environment and evaluation of the cultivar adaptation in subtropical India. The four cultivars (IR 36, Swarna, Swarn sub1, and Badshabhog) were grown in open field and in Open Top Chamber (OTC) of ambient CO_2 (≈390 ppm) and elevated CO_2 environment (25% higher than the ambient) during wet season (June–November) of the years 2011 and 2012 at Kharagpur, India. The genotype coefficients; P1 (basic vegetative phase), P2R (photoperiod sensitivity) and P5 (grain filling phase) were higher, but G1 (potential spikelet number) was lower under the elevated CO_2 environment as compared to their open field value in all the four cultivars. Use of the calibrated model of elevated CO_2 environment simulated the changes in grain yield of −13%, −17%, −4%, and +7% for the cultivars IR 36, Swarna, Swarna sub1, and Badshabhog, respectively, with increasing CO_2 level of 100 ppm and rising temperature of 1 °C as compared to the ambient CO_2 level and temperature and they were comparable with observed yield changes from the OTC experiment. Potential impacts of climate change were simulated for climate change scenarios developed from HadCM3 global climate model under the Intergovernmental Panel on Climate Change Special Report on Emission Scenarios (A2 and B2) for the years 2020, 2050, and 2080. Use of the future climate data simulated a continuous decline in rice grain yield from present years to the years 2020, 2050 and 2080 for the cultivars IR 36 and Swarna in A2 as well as B2 scenario with rising temperature of ≥0.8 °C. Whereas, the cultivar Swarna sub1 was least affected and Badshabhog was favoured under elevated CO_2 with rising temperature up to 2 °C in the sub-tropical climate of India.

1. Introduction

Increase in atmospheric temperature due to increased levels of greenhouse gas, mainly carbon dioxide has direct or indirect effect on food production (Garg et al., 2001; Krupa, 2003; Aggarwal, 2003; Kang et al., 2009). Despite technological advances, such as improved cultivars, genetically modified organisms, and precise irrigation systems, weather is still a key factor influencing agricultural productivity. At the plant level, a higher CO_2 concentration increases photosynthesis, growth, development, and yield of a wide range of cultivated C3 crops (Long et al., 2004, 2006; Ainsworth and Long, 2005; Ainsworth, 2008). Rice being a C3 crop, its biomass increases up to 40%, under elevated CO_2 (Baker et al., 1996; Ziska et al., 1997). In the absence of temperature increase, many studies have shown increase in the yield of rice with doubling of CO_2 level (Kim et al., 2003; Baker et al., 1992; Liu et al., 2008; Yang et al., 2009; Razzaque et al., 2011; Madan et al., 2012). However, despite these beneficial effects, the combined increase in temperature and variability of rainfall would considerably affect the rice yield. Rice becomes sterile if exposed to temperatures above 35 °C for more than 1 h during flowering and consequently produces no grain. Under climate change scenarios, the rising temperature nullifies the positive effect of increased CO_2 concentration on rice yield as reported by several researchers (Peng et al., 2004; Sheehy et al., 2006; Krishnan et al., 2007; Masutomi et al., 2009; Mohammed and Tarpley, 2009).

Crop production system involving fertilizer management, pest control, genotype, environment, and cultural practices is complex and conducting trials that take all these factors into account becomes increasingly complex and expensive. Suitably validated crop simulation models could be used to test many such combinations in a brief time with limited expense. Such simulations can adequately describe relative trends in yields caused by environmental

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Table 1
Soil properties of the experimental site at Kharagpur, India.

Soil depth (cm)	Clay (%)	Silt (%)	Sand (%)	Organic carbon (%)	pH in water	Total nitrogen (%)
0–5	14.3	26.2	59.5	0.5	6.3	0.05
5–20	14.3	26.2	59.5	0.4	6.3	0.04
20–40	27	20.2	52.8	0.1	6.5	0.01
40–60	28.6	19.2	52.2	0.1	6.7	0.01

variation (Penning de Vries et al., 1989). Models for complex crop system simulations aims to be dynamic rather than static, deterministic rather than stochastic and mechanistic rather than empirical (Wang, 1997). Mechanistic models offer more options to improve the system and to understand processes and their interactions. Many such crop models are available in Decision Support System for Agrotechnology Transfer (DSSAT) (Jones et al., 2003), that was developed by the International Benchmark Sites Network for Agrotechnology Transfer (Uehara and Tsuji, 1993) at the University of Hawaii. CERES (Crop Environment Resource Synthesis) model of the DSSAT simulates growth, development, nutrient uptake and yield of cereal crops considering the effect of weather, crop management, crop genetics, and soil water, C and N content.

Using CERES-Rice model, many researchers have reported the climate change impact on rice production (Babel et al., 2011; Kumar et al., 2010; Wikarmpapraharn and Kositsakulcha, 2010; Swain and Thomas, 2010; Gouranga et al., 2009; Yao et al., 2007). However, a well validated location specific management option for climate change adaptation in rice production system is lacking. Location specific cultivar, planting time and nutrient management adaptations needs detailed investigation for reducing the climate change impacts on rice production of tropical and subtropical climate, the major producer and consumer of rice. Varying cultivars of rice will show variable response to elevated CO_2 and rising temperature because of differing capacity in plant assimilation of atmospheric CO_2 via photosynthesis. The simulation of rice yield for climate change scenarios is generally based on calibration of the model parameter of desired cultivar for current weather condition and its subsequent application for climate change scenarios. It is essential to understand the effect of climate change scenarios on growth, phenology and yield of cultivars through controlled environmental experiments under elevated CO_2 level and accordingly estimate the model parameters for their use under climate change scenarios. In the present investigation, we used experimental facility and crop simulation model to calibrate genotype coefficient of CERES-Rice model for four rice cultivars grown under elevated CO_2 environment as in Open Top Chamber and to evaluate the cultivar adaptation to climate change in subtropical India.

2. Materials and methods

Field experiments were carried out in the research farm of Agricultural and Food Engineering Department, Indian Institute of Technology Kharagpur, Kharagpur (22°19′ N latitude and 87°19′ E longitude) India for calibration and validation of CERES-Rice model for elevated CO_2 environment. Soil of the location is red lateritic with sandy loam in texture, which is taxonomically grouped under the group 'Haplustalf'. The soil properties of the experimental site used for crop simulation are given in Table 1. The climate of Kharagpur is classified as humid and subtropical. It is characterized by hot and humid in summer (April and May), rainy during June–September, moderately hot and dry in autumn (October and November), cool and dry in winter (December and January) and moderate spring in February and March. The site receives an average annual rainfall of 1400 mm with an occurrence of 70–75% of the total rainfall in the monsoon months (June–October). The average daily temperature varies between 21 °C in December/January and 32 °C in May/June.

2.1. Experimental setup

The experiment for calibration and validation of CERES-Rice model under elevated CO_2 environment was conducted during wet season (June–November) of the years 2011 and 2012 in Open Top Chambers (OTCs). Open Top Chambers, made up of polycarbonate sheets are the most widely used and precise experimental method for exposing field grown plants to elevated CO_2 and other atmospheric gases. Four popular rice cultivars selected for the experiment were IR 36, Swarna, Swarna sub1 and Badshabhog. The cultivars IR 36 of medium duration (110–120 d) type and Swarna of long duration (140–150 d) type are commonly grown in the region. The cultivar Swarna sub1 (140–150 d), similar in nature to Swarna is a recent introduction in the region as an emerging cultivar, which has high tolerance to flood/submergence condition. The cultivar Badshabhog (150–160 d), an aromatic rice with lower yielding potential as compared to rest cultivars, is grown to a limited extent. Differences in physiological characteristics of these cultivars are given in Table 2. These four cultivars were grown with two replications in open field and in two OTCs as one ambient and the other elevated CO_2 environment. The field area (4 m × 4 m) of the OTC was divided into eight equal plots of size 1.8 m × 1 m, where each rice cultivar was grown. The plots were separated by inserting aluminium sheets up to 75 cm inside the soil and 25 cm above the soil to restrict water and nutrient movement between the plots. Rice seedlings of 25 days old were transplanted on 27th July in 2011 and on 15th July in 2012 with 2–3 seedlings per hill in a spacing of 20 cm × 15 cm. All the cultivars were grown with their recommended nutrient (NPK) management through chemical fertilizer (CF) in open field and OTCs. The CF dose as N:P_2O_5:K_2O were 100:50:60 kg ha^{-1} for IR 36/Badshabhog and 120:50:60 kg ha^{-1} for Swarna/Swarna sub1. The required amount of CF as N, P and K were supplied through urea containing 46% N, single super phosphate (16% P_2O_5) and muriate of potash (60% K_2O), respectively. Full dose of P and K were applied as basal at 1 day before transplanting of rice and were well incorporated in the soil. Nitrogen was applied in four equal splits at basal, active tillering, panicle initiation and flowering stage of the cultivars. Standing water height of minimum 1 cm was maintained in the field from transplanting to dough stage of the crop.

2.2. Plant sampling

Plant samples were collected from transplanting to harvest at 20 days interval. For this purpose, non-destructive observations on tiller numbers of 20 hills of a plot, leaving two border rows, were recorded, and the average number of tillers of representative hill was established (Thyagarajan et al., 1995). From these 20 hills, one hill with average tiller number was considered as sample hill. After collection, the above ground plant samples were cleaned and washed in water to remove surface contamination and separated into stems (leaf sheath + stem), leaves and panicles. Thereafter, the plant parts were kept in paper packets which in turn placed in an oven for drying. All these plant samples were oven dried at 70 °C till