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Effect of elevated $[CO_2]$ and nutrient management on wet and dry season rice production in subtropical India

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ABSTRACT

The present experiment was conducted to evaluate the effect of elevated $[CO_2]$ with varying nutrient management on rice–rice production system. The experiment was conducted in the open field and inside open-top chambers (OTCs) of ambient $[CO_2]$ ($\approx$390 μmol L^{-1}) and elevated $[CO_2]$ environment (25% above ambient) during wet and dry seasons in 2011–2013 at Kharagpur, India. The nutrient management included recommended doses of N, P, and K as chemical fertilizer (CF), integration of chemical and organic sources, and application of increased (25% higher) doses of CF. The higher $[CO_2]$ level in the OTC increased aboveground biomass but marginally decreased filled grains per panicle and grain yield of rice, compared to the ambient environment. However, crop root biomass was increased significantly under elevated $[CO_2]$. With respect to nutrient management, increasing the dose of CF increased grain yield significantly in both seasons. At the recommended dose of nutrients, integrated nutrient management was comparable to CF in the wet season, but significantly inferior in the dry season, in its effect on growth and yield of rice. The $[CO_2]$ elevation in OTC led to a marginal increase in organic C and available P content of soil, but a decrease in available N content. It was concluded that increased doses of nutrients via integration of chemical and organic sources in the wet season and chemical sources alone in the dry season will minimize the adverse effect of future climate on rice production in subtropical India.

1. Introduction

Climate change resulting from increasing atmospheric temperature due to increasing levels of greenhouse gases, mainly $[CO_2]$, and variation in rainfall has direct and indirect effects on global food production [1]. As CO_2 is an essential substrate for photosynthesis, increasing $[CO_2]$ will strongly affect agricultural production and global food security [2,3]. Increased $[CO_2]$ increases the rate of photosynthesis of C_3 crops at the cellular level through increased carboxylation and decreased oxygenation, both catalyzed by ribulose-1,5-bisphosphate carboxylase [2]. An increase in photosynthetic rates ultimately increases the biomass production and yield of agricultural crops [4,5]. Several studies have been conducted in recent years to characterize the effects of elevated $[CO_2]$ on rice growth and yield in open-field and controlled-environment chamber experiments [6,7]. Their

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results have shown that increased [CO_2] would increase rice yield, as rice is a C_3 species and generally responds positively to elevated [CO_2] by increasing its carbon assimilation rates. In the absence of temperature rise, several studies have shown increased yields of food grains with increased [CO_2] [8–10]. However, despite this favorable effect, the combined increase in temperature and variation in rainfall will markedly affect food grain production. Under climate change scenarios, rising temperature nullifies the positive effect of increased [CO_2] concentration on grain yield of cereal crops [11–13]. This effect is due to impaired pollination that leads to increased spikelet sterility at high temperatures.

The effect of high temperature on crop growth is expected to be region-specific, because of differing temperature sensitivity of crops in different regions. In tropical and subtropical latitudes, the increased temperature due to global warming will probably be near or above the optimum temperature range for the physiological activities of rice [14,15]. Warming will thus impair rice growth and cause spikelet sterility leading to grain yield reduction [16]. Higher air temperature also affects soil health: for example, warmer conditions enhance the decomposition of organic matter and increase the rates of other chemical and biological processes that affect inherent soil fertility [17] and thereby food production.

Rice is the second most important food crop in the world, grown on 145 million ha with an annual production of 730 million tons of grain [18]. In India, rice is grown on 44 million ha, 28% of the world rice area, contributing 22% of rice grain production [18]. Rice in India is grown mainly during the wet season (June–November) as a rainfed crop receiving the monsoon rain. Besides the wet-season crop, rice is also grown during the dry season (January–May) with irrigation, a practice more common in eastern India in the subtropical climate. The rice production of both rainfed and irrigated ecosystems is highly vulnerable to climate change, and the productivity of rice cultivation in India has declined since the 1990s in comparison with the rate of population growth [19].

The food grain production of tropical and subtropical countries including India is likely to be severely affected under future climate scenarios, complicating the food security of the developing world. This forecast is due to the generally predicted deleterious effects on agriculture, particularly in tropical and subtropical countries [20–22]. It is thus important to predict the effect of elevated [CO_2] and temperature on growth and yield of rice and changes in soil fertility status, using controlled-environment experiments for development of suitable agro-adaptations to climate change. In the present study, we used open-top chamber (OTC) field experimental facility to characterize the effect of elevated [CO_2] with varying nutrient management on rice growth, yield, and nutrient use efficiency and changes in soil chemical properties of rice–rice production systems in subtropical India.

2. Material and methods

2.1. Experimental site

Field experiments for characterizing the effect of elevated [CO_2] on growth, yield, and nutrient use efficiency of rice crop and analysis of changes in soil chemical properties were performed during the wet season (June–November) and dry season (January–May) in 2011–2012 and 2012–2013 on the research farm of the Agricultural and Food Engineering Department, Indian Institute of Technology Kharagpur, Kharagpur (22°19′N latitude and 87°19′E longitude), India. Soil at the location is red lateritic with sandy loam texture, low in organic C and available N content, medium in available P, and low in available K content. The detailed physical and chemical characteristics of the soil of the experimental field are presented in Table 1. The climate of Kharagpur is humid and subtropical. The location receives an average annual rainfall of 1600 mm with an occurrence of 70–75% of the total rainfall in the wet season (June to November). The average maximum temperature ranges from 25.8 °C in December/January to 36.0 °C in April/May. The average minimum temperature ranges from 13.3 °C in December/January to 25.9 °C in June.

2.2. Experimental details

The field experiments were performed in the open field and in OTCs. OTCs, made of polycarbonate sheets having a minimum of 80% light transmittance, are the most widely used and precise experimental method for exposing field grown plants to elevated [CO_2] and other atmospheric gases. An experiment varying [CO_2] environment and nutrient management was conducted during the wet and dry seasons of 2011–2012 and 2012–2013. Following are the treatment details of the [CO_2] environmental design and nutrient management.

Factor 1: [CO_2] environmental (E) design (3 levels)

E1—Open field,
E2—OTC with ambient [CO_2] level ([CO_2] ≈ 390 μmol L^{-1}) (ambient), and
E3—OTC with [CO_2] level 25% higher than the ambient ([CO_2] ≈ 490 μmol L^{-1}) (elevated [CO_2])

The desired [CO_2] level in OTC was maintained with a computer-based data acquisition system, as explained later in the instrumentation section.

Factor 2: nutrient (N) management (5 levels)

N1—Chemical fertilizer (CF) at 100% recommendation of N, P, and K via soil application: CF100
N2—Integrated nutrient management of CF at 50% recommendation of N, P, and K with organic fertilizer (OF) at 50% N recommendation: CF50 + OF50
N3—Integrated nutrient management of CF and OF with conservation technology (CT): CF50 + OF50 + CT
N4—CF100 via soil application (SA) of full P and K and 85% N and foliage application (FA) of remaining 15% N: SA85 + FA15
N5—CF at 125% recommendation of N, P and K through soil application: CF125

The recommended CF100 dose of nutrients as $N:P_2O_5:K_2O$ was 120:50:60 kg ha^{-1} for both wet and dry seasons. The OF sources were farmyard manure (FYM), sesbania as in-situ green manuring, and Azotobacter. Sesbania seed at 30 kg per