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Impact of elevated CO_2 concentration on inter-subspecific hybrid rice cultivar Liangyoupeijiu under fully open-air field conditions

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ABSTRACT

Hybrid rice cultivar plays an important role in rice production system due to its high yield potential and resistance to environmental stress. Quantification of its responses to rising CO_2 concentration ([CO_2]) will reduce our uncertainty in predicting future food security and assist in development of adaptation strategies. Using free air CO_2 enrichment (FACE), we measured seasonal changes in growth and nitrogen (N) uptake of an inter-subspecific hybrid rice cultivar Liangyoupeijiu grown under two levels of [CO_2] (ambient and elevated by 200 μmol mol^{-1}) and two levels of N fertilization in 2005–2006. Average across the 2 years, FACE increased crop growth rate similarly by 22%, 24% and 23% in the periods from transplanting to panicle initiation (PI), PI to heading and heading to maturity, which was mainly attributed to an increase in green leaf area index rather than the greater net assimilation rate. Grain yield increased greatly under FACE as a result of similar contributions by panicle number per unit area, grain number per panicle and individual grain yield. Final aboveground N acquisition showed a 10.4% increase under FACE, which resulted from enhanced N uptake at both vegetative and reproductive growth stages. Compared with previous FACE studies on final productivity of two inbred japonica cultivars, inter-subspecific hybrid cultivar appears to profit more from elevated [CO_2], which mainly resulted from its greater enhancement in photosynthetic production during reproductive growth due to a lack of N limitations late in the season.

1. Introduction

Empirical records provide incontestable evidence of global changes; foremost among these changes is the rising atmospheric carbon dioxide concentration ([CO_2]), which is projected to continue rising to at least 550 μmol mol^{-1} by 2050 (Current Intergovernmental Panel on Climate Change, 2007). In contrast to other aspects of global climate change (i.e., high temperatures, rising ozone concentrations and drought stress), rising [CO_2] is unique in being globally almost uniform and has been shown to stimulates the photosynthesis, growth and yield of world major food crops (Kimball et al., 2002). As a result, Parry et al. (2004) singled out its effect as the largest uncertainty in projecting future global food supply. With an annual production of about 0.6 billion tonnes, rice (*Oryza sativa* L.) is and will continue to be one of the most important food source for the global population, which is projected to grow from 6.6 billion today to 8.7 to 11.3 billion in 2050 (Bengtsson et al., 2006). Therefore, accurate quantification of rice productivity and development of adaptation strategies under anticipated changes in the atmospheric [CO_2] are increasing important for future rice food supply.

Quantification of genotypic variation in growth and productivity responses of rice to elevated [CO_2] and the basis for such variation is a crucial step in any effort to optimize grain yield as atmospheric [CO_2] continues to increase. However, in surveying the existing CO_2 literatures on rice growth and productivity, we found all researches have just focused on the responses of inbred rice cultivars including japonica (Imai et al., 1985; Seneweera et al., 1996; Seneweera and Conroy, 1997; Kim et al., 1996, 2001, 2003a,b; Yang et al., 2006a,b) and indica type cultivars (Baker and Allen, 1993; Ziska et al., 1997; Moya et al., 1998), with no attention given to another important genotype: hybrid rice cultivars, which are now widely used to attain high and stable grain yields and accounts for more than 50% of the rice planted area in recent years in China (International Rice Research Institute, 2007). Compared with inbred rice cultivars, hybrid ones exhibit higher speed of tiller occurrence, and relatively higher growth rate (Ling et al., 1994; Xie et al., 1996). Previous studies on C_3 species (other than rice) showed that inherently fast-growing species responded more strongly than slow-growing species (see reviews by Poorter, 1993).

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This phenomena suggest the likelihood of greater growth and productivity enhancement under elevated [CO_2] for hybrid versus inbred rice cultivars. Accurate quantification of such enhancement, especially under a natural, undisturbed conditions, will greatly improve our ability to predict rice productivity responses to rising [CO_2], and increase our potential to adapt rice crops to future high [CO_2].

Over time, the relative effect of elevated [CO_2] on growth of rice crops is reported to be changed with increasing duration of CO_2 exposure. Previous CO_2 experiments on inbred rice cultivars have documented that growth enhancement due to elevated [CO_2] generally decreases as a crop ages (Kim et al., 2003b; Sakai et al., 2006), however, this decline can be alleviated even reversed by adjustment in N strategies (e.g., a greater amount or proportion of N applied later in the season; use of controlled-release N fertilizer) and water management (i.e., earlier and/or longer summer drainage period) (Yang et al., 2006a, 2007, 2008). Nitrogen (N) is the most important soil nutrient contributing to plant growth and yield (Ling et al., 1994), and it plays an important role in plant responses to [CO_2]: the ability to respond and maintain growth enhancement in elevated [CO_2] is largely dependent on adequate supply of nutrient (Ziska et al., 1996; Kim et al., 2003a,b; Yang et al., 2007). Compared with inbred rice cultivars, hybrid ones generally exhibit strong ability to absorb N late in the season (Ling et al., 1994), which suggests that hybrid rice cultivars potentially show a relatively strong growth responses to elevated [CO_2] late in the season than inbred rice cultivars. Such a hypothesis has never been tested before.

In order to further break the yield ceiling, China started a nationwide mega project for the development of "super" hybrid rice in 1996 (Cheng et al., 1998). Today, many "super" hybrid rice varieties have been released (Peng et al., 2004). In this study, Liangyoupeijiu, one of the most popular 'super' hybrid rice variety (a single cross of two parental lines) in China, was examined under fully open-air field conditions over two growing seasons (2005–2006). The primary objective of this study was to determine the interactive effects of elevated [CO_2] and N supply on growth and N uptake of Liangyoubeijiu, and elucidate the linkages between them. In addition, genetic differences in growth responses to high CO_2 and its possible basis were also discussed based on available data from current and previous rice free air CO_2 enrichment (FACE) experiments.

2. Materials and methods

2.1. Experimental site

As a part of the long-term FACE project in China, this study was conducted in Jiangdu county, Yangzhou city, Jiangsu province, China (119°42′0″E, 32°35′5″N). This site has been in continuous cultivation for more than 1000 years with rice–wheat or rice–rapeseed rotation. The soil is Shajiang Aquic Cambosols with a sandy-loamy texture. Relevant soil properties are as follows: soil organic C (SOC) 18.4 g kg^{-1}, total N 1.45 g kg^{-1}, total P 0.63 g kg^{-1}, total K 14.0 g kg^{-1}, available P 10.1 mg kg^{-1}, available K 70.5 mg kg^{-1}, and pH 7.2. The station, 5 m above sea level in elevation, sits in the subtropical marine climatic zone with mean annual precipitation being 1100–1200 mm, annual evaporation 1100 mm, annual mean temperature 14.9 °C, a total annual sunshine hours more than 2000 h and a frostless period more than 230 d.

2.2. CO_2 treatment

The China Rice FACE system has six plots located in different paddies having similar soils and agronomic histories. Three plots were randomly allocated for the elevated CO_2 treatments (hereinafter called FACE plots) and three for the ambient treatments (hereinafter referred to ambient plots). In the FACE plots, the plants were grown within 12 m diameter 'rings' in which pure CO_2 gas was released from peripheral emission tubes set 0.5 m above the canopy. The ambient plots had no ring structures, and the plants were grown in ambient [CO_2]. The target [CO_2] at the centre of the FACE plots throughout the rice growth season was controlled to 200 μmol mol^{-1} above that of the ambient plots. The actual daily [CO_2] average over the season with standard deviation were 565 ± 39 (2005) and 564 ± 40 μmol mol^{-1} (2006) in the FACE plots and 374 ± 21 μmol mol^{-1} (2005) and 378 ± 23 μmol mol^{-1} (2006) in the ambient plots. Adjacent plots were buffered to avoid treatment cross-over. A detailed description of this FACE system is provided by Okada et al. (2001) and Liu et al. (2002).

2.3. N treatment

Liangyoupeijiu, a two-line hybrid variety of Peiai 64S × 9311, was tested in this study. It is recently bred and one of the most popular inter-subspecific hybrid rice in China (Peng et al., 2004). Standard cultivation practices as commonly performed in the area were followed in all plots. Rice seeds were sown on 20 May in 2005 and 2006. The seedlings grown under ambient air were manually transplanted at a density of one seedling $hill^{-1}$ into the FACE and ambient plots on 15 June in 2005 and 2006. Hills and rows were 16.7 and 25 cm, respectively (24 hills m^{-2}). Two levels of N were supplied as urea (N, 46.3%) and compound chemical fertilizer ($N:P_2O_5:K_2O$ = 15:15:15, %): low (LN, 12.5 g N m^{-2}) and high (HN, 25 g N m^{-2}). For all N levels, P and K were both applied as compound chemical fertilizer at an equal rate of 7 g m^{-2}. N was applied as a basal dressing (N incorporated in soil surface) and as sidedressing at early tillering (60% of the total) and at panicle initiation (PI) (40% of the total), while P or K was both applied as basal dressing. The rates and dates of N, P and K fertilizer applications are listed in Table 1. The LN subplots were separated from the rest of the plot (which received HN) by a 30-cm-tall PVC barrier to avoid N contamination. The paddy fields were submerged with water, about 5 cm in depth, from 13 June to 10 July, drained dry several times from 11 July to 4 August, and then flooded with intermittent irrigation from 5 August to 10 d before harvest.

2.4. Sampling and measurements

Areas of the crop were destructively sampled at different times over the season. Plants were sampled at PI (47 d after

Table 1
Timing and application rates (g m^{-2}) of urea and compound fertilizers in the LN and HN plots over two rice cropping seasons (2005–2006).

Treatment	First fertilization[a]		Second fertilization[b]		Third fertilization[c]	
	Urea	Compound Fertilizer	Urea	Compound fertilizer	Urea	Compound fertilizer
LN	1.08	46.67	0	0	10.8	0
HN	4.32	46.67	12.96	0	21.6	0

[a] The first fertilization was applied as basal dressing on 15 June (i.e., 1 d prior to transplanting).
[b] The second fertilization was applied as tillering fertilizer on 21 June.
[c] The third fertilization was applied as ear fertilizer on 28 July.