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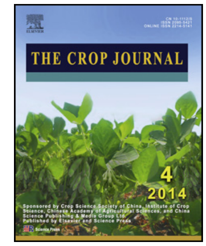


# Effects of free-air $CO_2$ enrichment on adventitious root development of rice under low and normal soil nitrogen levels

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ABSTRACT

Free air $CO_2$ enrichment (FACE) and nitrogen (N) have marked effects on rice root growth, and numerical simulation can explain these effects. To further define the effects of FACE on root growth of rice, an experiment was performed, using the hybrid indica cultivar Xianyou 63. The effects of increasing atmospheric $CO_2$ concentration [$CO_2$], 200 μmol mol$^{-1}$ higher than ambient, on the growth of rice adventitious roots were evaluated, with two levels of N: low (LN, 125 kg ha$^{-1}$) and normal (NN, 250 kg ha$^{-1}$). The results showed a significant increase in both adventitious root number (ARN) and adventitious root length (ARL) under FACE treatment. The application of nitrogen also increased ARN and ARL, but these increases were smaller than that under FACE treatment. On the basis of the FACE experiment, numerical models for rice adventitious root number and length were constructed with time as the driving factor. The models illustrated the dynamic development of rice adventitious root number and length after transplanting, regulated either by atmospheric [$CO_2$] or by N application. The simulation result was supported by statistical tests comparing experimental data from different years, and the model yields realistic predictions of root growth. These results suggest that the models have strong predictive potential under conditions of atmospheric [$CO_2$] rises in the future.



## 1. Introduction

The rice root system is a vital organ for water and nutrient acquisition, and root number and activity affect the growth of aerial parts and economic yield [1]. Rice roots are relatively short, and most are distributed in the plow horizon [2,3]. Differences in root distribution among different rice varieties have been found [4]. The architecture of the root system is

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also well known to be a major determinant of root function in the acquisition of soil resources, and the increase of the volume of the soils explored by the roots, as a result of continuous branching, may reflect the plant's adaptive ability to make best use of unevenly distributed water and nutrients [5]. In recent years, many studies of the effects of different water and fertilization levels on rice root growth have been performed. The growth process and distribution of rice roots and the effects of various cultivation conditions on root system are described by the results of these studies. Under treatment with high nitrogen (N), the dry weight of roots was higher than that under low N fertilization, and moderate water favored the increase of root dry weight [2,5–10].

Free air $CO_2$ concentration is one of the important factors affecting root development [11–15]. As it is difficult to alter $CO_2$ concentration under field conditions, most information on the responses of rice yield to elevated $CO_2$ has been obtained from studies in well-controlled non-field conditions, such as in greenhouses [16], soil–plant–atmosphere research units [17], temperature-gradient chambers [18,19] and open-top chambers [20]. However, these experimental conditions, which are different from natural growing environments (field conditions) in combination with the border effects associated with small plots, have been shown to modify the responses of plants to increasing [$CO_2$] [21,22]. FACE experiments, conducted in fully open-air field conditions without altering microclimatic and biotic variables, represent our best simulations of the future high $CO_2$ environment. Over the last decade, only two large-scale (12 m × 12 m plots) replicated rice FACE experiments have been conducted worldwide (1997–2006). Both experiments used a similar FACE technology and employed the same target [$CO_2$], 570 μmol mol$^{-1}$ [23–25].

There have been reports on the effects of elevated [$CO_2$] and N supply on the growth, nutrient uptake, root development, and yield of inbred japonica cultivars [13,14,25–29], but no simulated prediction for root number and length has been made. Compared with conventional rice cultivars, hybrid rice cultivars exhibit better tillering ability, thus a relatively higher growth rate. The effects of FACE and N on root growth may be different. In the present study, the hybrid rice cultivar Shanyou 63, the most widely used hybrid rice variety in China for the past 15 years [30], was used to study the effects of FACE under two N levels on root number and length, and the results were used for model development. The models may provide information for root growth control and high-yield cultivation of rice.

## 2. Materials and methods

### 2.1. *Experiment site and its weather*

The experiment was conducted in Xiaoji, Yangzhou, Jiangsu, China (32°35′5″ N, 119°42′ E) in 2005 and 2006. The farm used in this study had fluvisol soil (local name, Qingni soil) with annual mean precipitation of 980 mm, evaporation of 1100 mm, temperature of 14.9 °C, total sunshine hours of 2100 h, and frostfree period of 220 d. The physical and chemical properties of the soil were as follows: soil organic carbon (SOC) 18.4 g kg$^{-1}$, total N 1.45 g kg$^{-1}$, total P 0.63 g kg$^{-1}$, total K 14 g kg$^{-1}$, available P 10.1 mg kg$^{-1}$, available K 70.5 mg kg$^{-1}$, sand (0.02–2.00 mm) 578.4 g kg$^{-1}$, silt (0.002–0.020) 285.1 g kg$^{-1}$, clay (<0.002 mm) 136.5 g kg$^{-1}$, and pH 7.2.

### 2.2. *FACE system*

The FACE system comprised six FACE plots located in different fields with similar soil and agronomic histories. Of these plots, three were allocated for FACE experiments (hereafter called E-[FACE]) and another three for ambient treatments (hereinafter called A-[FACE]). To reduce the influence of $CO_2$ emission, the distance between E-[FACE] plots and A-[FACE] was more than 90 m. Each E-[FACE] plot was designed as an octagon with a largest diameter of 12.5 m. In the E-[FACE] plots, pure $CO_2$ gas was released from peripheral emission tubes and the [$CO_2$] was about 570 μmol mol$^{-1}$. The FACE treatment was controlled by a computer system. A-[FACE] plots had no octagon structures and the [$CO_2$] was about 370 μmol mol$^{-1}$.

### 2.3. *Crop cultivation*

Seeds of Shanyou 63 were sown in a nursery on May 20. Seedlings were manually transplanted at a density of one seedling per hill into E-[FACE] and A-[FACE] on 15 June. Hill space was 16.7 cm × 25.0 cm (equivalent to 24 hills m$^{-2}$). Two levels of N were supplied as urea: low (LN, 125 kg ha$^{-1}$) and normal (NN, 250 kg ha$^{-1}$). Half of the E-[FACE] and A-[FACE] plots had the LN regime and the other half NN. N was applied as basal fertilizer one day before transplanting, as side-dressing at early tillering on 21 June (60% of the total), and at panicle initiation on 28 July (40%). Phosphorus (P) and potassium (K) were applied as basal fertilizer at equal rates of 70 kg ha$^{-1}$ on June 14. The paddy fields were flooded with water (about 5 cm deep) from June 13 to July 10, drained several times from July 11 to August 4, and then flooded intermittently from August 5 to 10 d before harvest. Disease, pests and weed were controlled according to standard practice.

### 2.4. *Plant sampling and measurements*

Fifty hills from different locations (three locations in each subplot) were selected to record the number of tillers at 14, 25, 44, 56, 73, and 90 d after transplanting. At the same time, a soil block around a plant with dimensions 25.0 cm × 16.7 cm × 20.0 cm was removed. The number of adventitious roots and total root length in every hill were recorded after washing with pure water.

### 2.5. *Data analysis and tests*

The experiment data was analyzed by MATLAB software and Microsoft Excel 2003. The root mean square error (RMSE) and relative root mean square error (RRMSE) between observed value and simulation value were used to describe the precision of the model. A 1:1 relation graph of the observed and simulated values was drawn based on this model. RMSE and RRMSE were expressed as follows:

$$\mathrm{RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(O_i - S_i)^2}$$