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RESEARCH PAPER

The Effects of the Elevated CO_2 Concentration and Increased Temperature on Growth, Yield and Physiological Responses of Rice (*Oryza sativa* L. cv. Junam).

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ABSTRACT

A global warming may have significant effect on physiology, development, growth and productivity of rice (Oryza sativa L. cv. Junam) due to increase in CO_2 concentration and temperature. This study was conducted to determine the effects of elevated CO_2 and temperature on the eco-physiological responses of rice. Rice plants were grown under AC-AT (ambient CO_2 + ambient temperature), AC-ET (ambient CO_2 + elevated temperature) and EC-ET (elevated CO_2 + elevated temperature) from May to October in 2009. Shoot length was high at AC-ET and root length was the highest at AC-AT and the lowest at EC-ET. Aboveground, and total biomass were the highest at AC-AT and the lowest at EC-ET. Belowground biomass and root:shoot ratio were higher at AC-AT than at AC-ET. Panicle length was decreased by elevated CO_2 and temperature. Panicle weight and no. of grains per panicle were higher at AC-AT and AC-ET than at EC-ET. Grain ripened ratio and weight of grain were not significantly affected by elevated CO_2 and temperature. Chlorophyll and nitrogen content were higher at AC-AT than at AC-ET and EC-ET. Nitrogen content was higher at AC-AT and AC-ET than at EC-ET and carbon content was not significantly affected by elevated CO_2 and temperature. C:N ratio was higher at EC-ET than at AC-AT and AC-ET.

From the result, it can be concluded that growth and yield of rice had negative response to global warming situation.

KEY WORDS : *Climate change, Oryza sativa L., Growth, Yield, Nitrogen, Chlorophyll*

INTRODUCTION

Climate change has had a discernible impact on global production of several major crops, rice, wheat and soybean so on [1]. Especially, growth and yield of rice plants are markedly affected by increased CO_2 concentration and temperature. Rice (*Oryza sativa* L.) is one of the most important crops in the world and the primary staple food in Asia .

Many studies have been conducted to examine the effects of elevated CO_2 and temperature on rice growth and yield during the past several decades [2, 3].

Imai *et al*. [4] demonstrated that doubling of the air CO_2 concentration resulted in an increase of vegetative growth of rice plants. Also, the panicle weight per plant and grain weight were increased 23-72% by elevated CO_2 and increased temperature. According to De Costa *et al*. [5], rice plants grown at a CO_2 concentration of 570ppm accumulated biomass faster than those grown under ambient CO_2 concentration during vegetative and grain filling stage.

While several studies have shown that increased CO_2 and high temperature can reduce growth and yield of rice [6]. Matsui and Omasa [7] showed that increasing temperature at flowering inhibits swelling of the pollen grains and therefore high temperature would induce spikelet sterility and increase the instability of the rice yield.

The physiological response of plant is affected by elevated CO_2 concentration and temperature. Among them, changes in nitrogen and chlorophyll content have been observed in many studies [8]. The significant alteration in their levels is likely to cause marked effects on the entire metabolism of plants [9]. Because the proteins of the Calvin cycle and thylakoids represent the majority of leaf nitrogen and chlorophyll content is the central part of the energy manifestation and can directly determine photosynthetic response and primary production [10, 11].

Nakano *et al*. [12] determined that total leaf nitrogen and chlorophyll content were decreased in the leaves of the rice plants grown at elevated CO_2 concentration and thus the growth under elevated CO_2 led to a decrease in the photosynthetic capacity. While Cheng *et al*. [13] reported that high night temperature significantly increased the N concentration in the stems, leaves and roots and elevated CO_2 significantly decreased N concentration in the ears.
Rice responses to climate change vary with region and rice cultivars. Hence, there is a need for more experiments on various cultivars of rice under global warming situation in many areas.
In this study, rice was grown under two CO_2 levels and two air temperature in three gradients during vegetative and reproductive stage. Junambyeo (*Oryza sativa* L. cv. Junam) used as experimental materials is a new japonica rice cultivar developed in 2006 and the most widely cultivated in the central region in Korea.
The objective of our study was to determine how growth and yield, physiological responses, namely chlorophyll, nitrogen and carbon content of Junambyeo responded to elevated CO_2 concentration and high temperature as well as their interaction.

MATERIALS AND METHODS

In May 2009, seeds of rice were pre-germinated. At about three-four leaf stage, six seedlings were transplanted to pot filled with sand. Rice plants were given additional fertilizer three times during the study period and grown under flooded conditions (2-3cm deep).
The study was determined in and out of glasshouse. The control (AC-AT) was located in glasshouse but two treatments (AC-ET and EC-ET) were out of glasshouse. In the AC-AT, the air is maintained at the ambient CO_2 concentration and temperature of the immediately surrounding air, which averages about 370-380ppm on a 24-hours basis. The EC-ET in glasshouse was maintained by inputting a small amount of pure CO_2 through two perforated plastic hose. In this way, the elevated CO_2 concentration was kept about twice higher than the ambient one amounting to 750~800ppm. LCi Ultra Compact Photosynthesis System (ADC 2005) was used to test the stability of the CO_2 concentration in the treatment. Mean temperature in AC-ET and EC-ET was about 1.5^0C and 3^0C higher relative to the control respectively. Air temperature was measured using data logger (Thermo recorder TR-71U, T&D Co., Japan) at same height in control and treatments during study period.
In October 2009, six plants in each pot were harvested, sorted into shoot, root, panicle and grains so on, and then dried in the shade for two days and measured.
Leaf samples were selected from the uppermost fully expanded leaves of rice grown under control and treatments. Leaf samples were dried for 2 days at 65^0C. After the leaves had been dried, their samples were pulverized into fine powders with a blender. The nitrogen and carbon content were determined by automatic elemental analyzer (Flash EA 1112 series, Thermo Flsher Scientific) at the Center for Research Facilities, Chungnam National University. The C:N ratio was calculated as carbon content to nitrogen content. Chlorophyll content measurement on leaves of rice was made with hand-held chlorophyll content meter (CCM-20, ADC Bioscientific), which measures the absorbance of a small portion of leaf using differential transmission at two wavelengths, 665 and 940nm.
Effects of elevated CO_2 and temperature on eco-physiological parameters of rice measured in this study were evaluated using one-way ANOVA and the differences were tested by a Fisher's least significant difference test. The data processing was performed with STATISTICA 8 (Statsoft Co. 2007).

RESULTS AND DISCUSSION

The aboveground and total biomass of rice reduced with increasing CO_2 concentration and temperature. Belowground biomass was higher at AC-AT than at AC-ET and EC-ET (Fig. 1). These results mean that carbon accumulation on vegetative organs decreased under elevated CO_2 and increased temperature. In contrast, Baker *et al*. [14] showed that shoot biomass and root biomass increased under increasing CO_2 concentration. According to Yang *et al*. [15], the final total biomass of rice was increased by 16% under elevate CO_2
Crop yield will be influenced by complex interactions between increase in atmospheric CO_2 concentrations and temperature in the future [16].

In our study, panicle length of rice was the highest at AC-AT and the lowest at EC-ET (Fig. 1). Weight of panicle and number of grains panicle was higher at AC-AT and AC-ET than at EC-ET. Number of tillers was decreased by elevated CO_2 and temperature. Ripened grain rate was not significantly affected by increasing CO_2 concentration and temperature. Weight of one grain gradually reduced with elevated CO_2 and temperature but the result was not statistically significant.

Table1. Chlorophyll content, nitrogen content, carbon content and C:N ratio of Junambyeo in leaves measured under three gradients (Fisher's least significant difference, p<0.05)

Character	Gradients		
	AC-AT	**AC-ET**	**EC-ET**
Chlorophyll content	9.30±3.42 ^{A}	6.94±1.90 ^{B}	5.58±1.91 ^{B}
Nitrogen content	1.22±0.07 ^{A}	1.31±0.03 ^{A}	0.90±0.08 ^{B}
Carbon content	39.77±0.34 ^{A}	39.56±0.33 ^{A}	39.71±0.65 ^{A}
C:N ratio	32.73±2.00 ^{B}	30.18±0.53 ^{B}	44.24±3.76 ^{A}

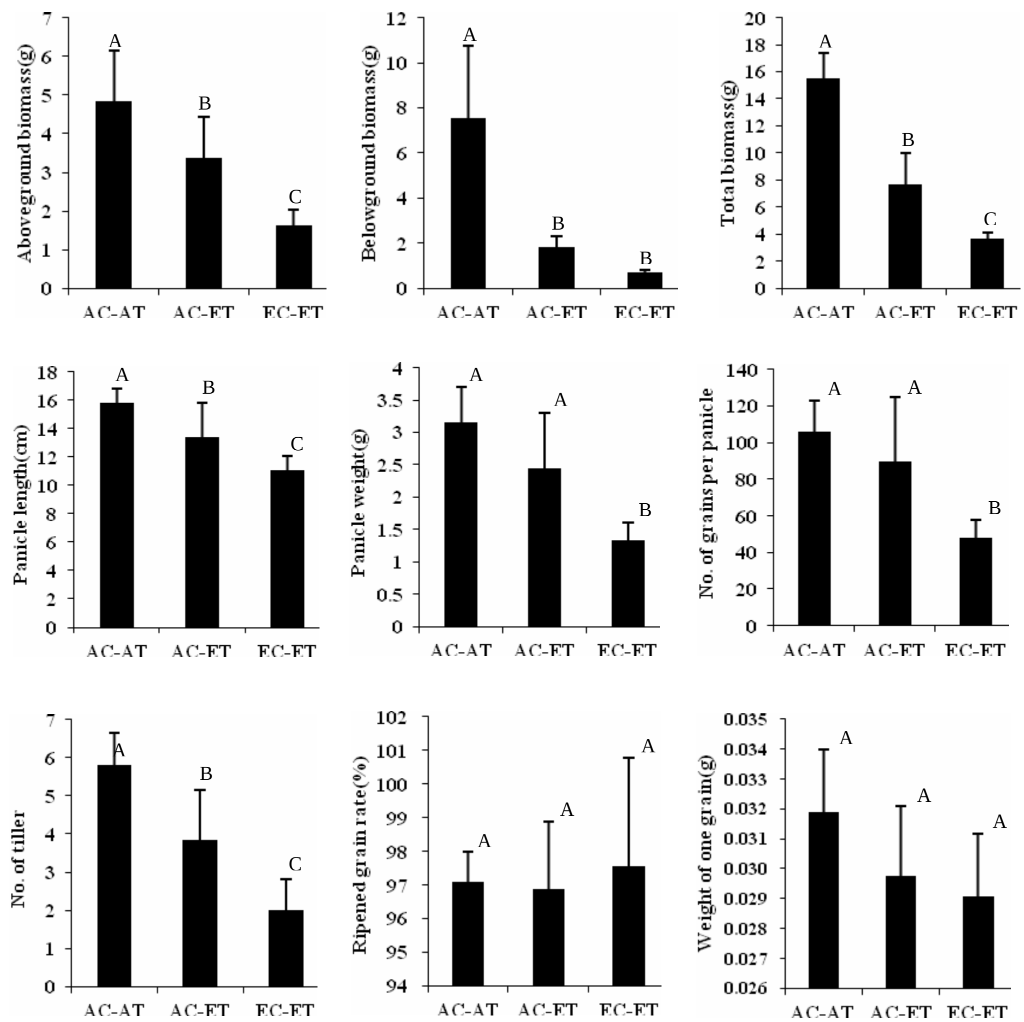

Fig 1. Growth and yield characteristics of Junambyeo under three gradients. Alphabets on the bars mean significantly different among environmental gradients level (Fisher's least significant difference, p<0.05).

Baker *et al.* [6] showed that grain yield of rice grown in elevated CO_2 treatment decreased from 10.4 to 1.0 Mg/ha with increasing temperature and the number of seeds per panicle declined. According to

Lawlor and Mitchell [17], 1 ℃ temperature increase during grain-filling shortens this period by 5% and proportionally reduces harvest index and grain yield. Chakrabarti *et al*. [18] determined that increasing temperature could limit rice yield by affecting pollen germination and grain formation. Those results are in agreement with the result of our study.

In general, growth and yield of rice tent to increase with elevated atmospheric CO_2 concentration while high temperature has a negative effect on rice response. Krishnan *et al*. [19] predicted that increase in temperature at all the CO_2 levels tested would cause a reduction in yield but an increase in CO_2 level at each temperature increment would increase yields using two crop simulation models. Baker *et al*. [6] showed that tillering of rice increased temperature treatment while grain yield increases owing to CO_2 enrichment were small. Thus grain yields were affected much more strongly by temperature than CO_2 treatment. According to Cheng *et al*. [20], ear dry weight was significantly increased by elevated CO_2 and decreased by high night temperature. These results mean that increase in air temperature often offsets the stimulation of rice biomass and grain yield due to elevated CO_2 concentration.

Judging from results of several studies, growth and yield of Junambyeo were more affected by temperature than CO_2 concentration in our study.

Nitrogen and chlorophyll content of plant's leaves is generally decreased by elevated CO_2 and temperature [9, 21].

In our study, chlorophyll and nitrogen content of Junambyeo decreased but C:N ratio of that increased under elevated CO_2 and temperature(Table 1). Carbon content of Junambyeo was not significantly affected by elevated CO_2 and temperature.

Nitrogen content of Junambyeo was 1.23% at AC-AT and 0.90% at EC-ET thus it was reduced by 36.6% under elevated CO_2 concentration and increased temperature. Similarly, Cheng *et al*. [13] determined that nitrogen content of rice leaves was 1.03% and 1.01% under AC-AT and EC-ET respectively but these results was not significantly affected by interaction with elevated CO_2 and high temperature. While at a high temperature treatment, elevated CO_2 concentration significantly reduced nitrogen content of rice leaves from 1.03% to 1.14%.

In agreement with our results, Cheng *et al*. [13] also showed that carbon content of rice was not significantly affected by elevated CO_2 and temperature.

According to Nakano *et al*. [12], chlorophyll content was decreased in the leaves of the plants grown at elevated CO_2 partial pressure. Sakai *et al*. [22] determined that nitrogen content of rice plants grown in elevated CO_2 treatment was significantly lower than in the plants grown under ambient CO_2 concentration. Those results are in agreement with the result of our study.

Many studies suggest that decreases in leaf nitrogen and chlorophyll content are often associated with reduced responses of leaf photosynthesis [12]. The decrease in chemical composition of leaves is crucial for the whole-plant growth under CO_2 enrichment and increased temperature. Hence, our results suggested that decreases in biomass accumulation of Junambyeo were caused by reduced leaf nitrogen and chlorophyll content under elevated CO_2 and temperature.

In couclusion, we determined that growth, yield and physiological responses of Junambyeo might be negatively influenced under global warming situation in the future.

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