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Effects of Elevated CO_2 and Temperature on Competition between Rice and *Echinochloa glabrescens* Seedlings

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ABSTRACT

The objective of this study was to determine how elevated CO_2 and temperature affected early growth and competition between direct seeded rice (*Oryza sativa*) and a common paddy weed (*Echinochloa glabrescens*). By using temperature gradient chambers, rice and *E. glabrescens* were grown for 5 weeks at ratios of 1:0, 3:1 and 0:1 at three temperatures (16.4° C, 19.8° C, and 22.2° C) and either in ambient (361ppm) or elevated (566ppm) CO_2. For both species, elevated CO_2 had no effect on mainstem leaf number while air temperature had a slight positive effect which was greater in *E. glabrescens* than rice. With elevated CO_2, rice leaf area index and plant height increased slightly in all species combinations but no increases were observed for *E. glabrescens*. For rice in all combinations, elevated CO_2 tended to increase the root and total biomass much more than any other growth parameters; the increases in root and total biomass resulting from elevated CO_2 ranged from 16% to 40%, depending on air temperature. At the lowest temperature, the decrease in rice biomass in combination with *E. glabrescens* was significantly greater at elevated CO_2 (18%) than ambient CO_2 (3%). At the highest temperature, however, the decrease in rice biomass at elevated CO_2 (22%) was less than that at ambient CO_2 (36%). The competitive ability of rice as measured by the decrease in biomass when grown in combination with *E. glabrescens* depended strongly on root growth and/or allocation. These results suggest that at higher temperatures, elevated CO_2 could enhance the competitive ability of direct seeded rice during early growth. However, at lower temperatures, the competitive ability of *E. glabrescens* seems to be greater.

Key words: competition, direct seeded rice, *Echinochloa glabrescens*, elevated CO_2, early growth.

INTRODUCTION

Recently, the importance of increasing atmospheric CO_2 concentrations, associated with its direct or indirect effects on crop productivity, has been recognized (Baker et al., 1990; Conroy et al., 1994; Imai et al., 1985; Kim, 1996a; Kim et al., 1996b). It is well documented that elevated CO_2 increases the growth and yield of various crop plants (Kimball, 1983). In plants with the C_3 photosynthesis pathway such as rice, the major driving force for the growth response to elevated CO_2 is thought to be higher photosynthetic rates and decreased photorespiration (Chollet et al., 1975; Baker & Allen, 1993). On the other hand, plants with the C_4 pathway do not usually respond to the same extent as C_3 plants to elevated CO_2 because they have a biochemical CO_2 concentrating mechanism within the leaf. Consequently, photosynthetic rates and growth of C_4 plants increase only slightly with elevated CO_2 (Conroy, 1992).

Rice is predominantly grown under flooded conditions in paddy fields where weeds can limit growth and yield. Consequently, it is important to determine how elevated CO_2 and temperature (as an indirect effect of increasing CO_2) will affect growth and competition between rice and weeds. However, there are few studies on this, particularly when plants are grown with natural daily and seasonal temperature variations.

In this study, rice and *E. glabrescens*, a common weed in rice crops which has a similiar growth pattern to rice, were exposed to elevated CO_2 and various temperatures. The objective of this study was to determine how elevated CO_2 and temperatures affect competition between direct seeded rice and *E. glabrescens* at an early growth stage when both leaf area expansion and root production are rapid.

MATERIALS AND METHODS

Air temperature and CO_2 control

The experiment was conducted in two temperature gradient chambers (TGCs) which were constructed originally to investigate cooling injury in rice, at the Tohoku National Agricultural Experiment Station, Morioka, Japan (described by Okada and Sameshima 1997). The TGCs were commercial greenhouses which were covered by a clear plastic film with a high transmissivity of long-wave radiation. The TGC dimensions were 27m in length, 5.8m in width at floor level and 2.9m in height. Both TGCs had air cooling (AH-16H, Hitachi) and heating (HK-3020, Lepon) systems at the air inlet and the outlet respectively. One TGC had a CO_2 enrichment facility at the air inlet.

Temperature gradient was controlled by regulating the speed of one of the three exhaust fans installed at the warm end of TGC. The exhaust capacity of one fan could be varied in three steps ranging from 0 to 350m^3/min by using an invertor, while the other fans ran constantly (90m^3/min). The major driving forces generating the temperature gradient in the TGC are solar energy and hot-air via air distributing ducts in the heat exchanger installed at the warm end of chamber. This heat exchanger was used to achieve the goal temperature gradient during cloudy days and at night time. The TGC system created the temperature gradient along the longitudinal axis, while maintaining the natural diurnal and seasonal fluctuations. The temperature difference between the air inlet (1m) and the outlet (23m) was controlled to maintain a 7° C gradient. Air temperatures in the TGCs were measured by aspirated platinun resistance thermometers located at points 1, 6.5, 12, 17.5 and 23m from the air inlet. Temperatures in the TGCs were measured at 10s intervals and stored in computer as 30 minute average values, using a 16 channels Green Kit 100 (ESD co., LTD). By linear interpolation based on these temperature data, air temperatures at any point in the TGC could be determined.

CO_2 concentrations in TGC were maintained at either ambient or ambient+200ppm (elevated CO_2, hereafter) throughout the day and night. Infrared CO_2 analyzers were used for CO_2 control (ZFP 9GC11, Fuji) and monitor (ZEP 5YA31, Fuji). Five CO_2 emission tubes (Kiriko R, Mitsui) with a different length (0.25-1.5m) were used for controlling the CO_2 concentrations in the elevated CO_2 TGC. We adopted a simple ON-OFF logic for controlling the CO_2 emission rate which depended mainly on air exhaust rate. CO_2 concentration in the TGCs was also measured at 10s intervals and stored in a computer as 30 min average values. Average CO_2 concentrations during the experiment were 361ppm (ambient) and 566ppm (elevated).

Plant culture and growth measurements

Rice (cv. Akitakomachi) and *E. glabrescens* were direct sown by hand into 5 liter pots filled with a Haplaquept soil on 14 and 15 May 1997, respectively. The seeded pots were placed at even distances (22 × 22cm) in the ambient and elevated CO_2 TGCs to form canopy-like conditions at 3 locations: 3 to 4.5, 12 to 13.5 and 21 to 22.5m from the air inlet. Figure 1 shows the change of average daily temperatures at 3, 12 and 21m during the experiment. At these points, seasonal average temperatures were 16.4 (3m, lowest temperature), 19.8 (12m, moderate temperature) and 22.2° C (21m, highest temperature). After emergence, seedlings were thinned to 6 or 8 plants per pot in order to establish a planting density of 124 or 165 plants per m^2, and flooded conditions were maintained during the experiment. There were three species mixtures having plant ratios of rice to *E. glabrescens* of 1:0, 3:1 and 0:1 within each pot. The experiment was designed as a completely randomized design with two replications. Before seeding, N, P and K were supplied at 10.4, 25.9 and 15.5g per m^2, respectively. Plants were harvested at 5 weeks after emergence. Plant height, leaf area, root and total biomass were measured. Student t-test was used to test for difference between treatments.

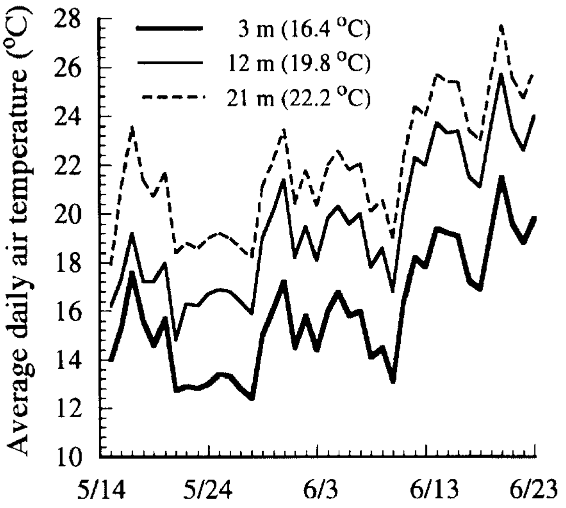

Fig. 1. Changes in average daily air temperature at points 3m, 12m and 21m from the air inlet of the temperature gradient chamber during the experiment. Temperatures in parenthesis indicate the average air temperature for the duration of experiment.

RESULTS AND DISCUSSION

CO_2 concentration had no influence on mainstem leaf number for rice and *E. glabrescens*, while air temperatures had a slight positive effect (Fig. 2). Mainstem leaf number was greater for *E. glabrescens* at all temperatures regardless of CO_2 concentration. These results indicate that leaf appearance rates for both species were not altered by elevated CO_2. This is in contrast to the data of Conroy et al.(1994) who observed that in the rice, leaf appearance rate was faster at elevated CO_2.

Figures 3a to l show plant height, leaf area index (LAI), root and total biomass for all mixtures grown at ambient and elevated CO_2 as a function of air temperature. At 19.8 and 22.2° C, rice plant height over all mixtures was slightly increased at elevated CO_2 but was not with lower temperatures (Fig. 3a,b). In *E. glabrescens*, no increase in plant height was observed at elevated CO_2, although it was greater with increased temperatures (Fig. 3c).

Elevated CO_2 increased LAI (60%) in rice but only at 19.8° C (Fig. 3d). In the 3:1 mixture, rice' s LAI also

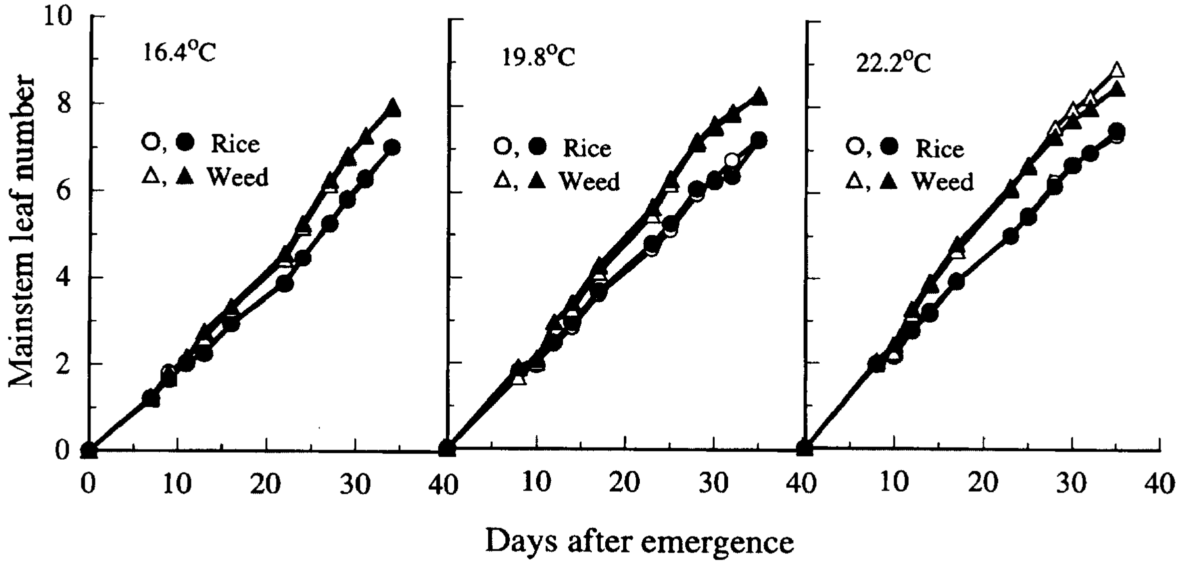

Fig. 2. Mainstem leaf number of rice and *E. glabrscens* exposed to ambient(open symbols) and elevated CO_2(closed symbols) as a function of days after emergence under different air temperatures.

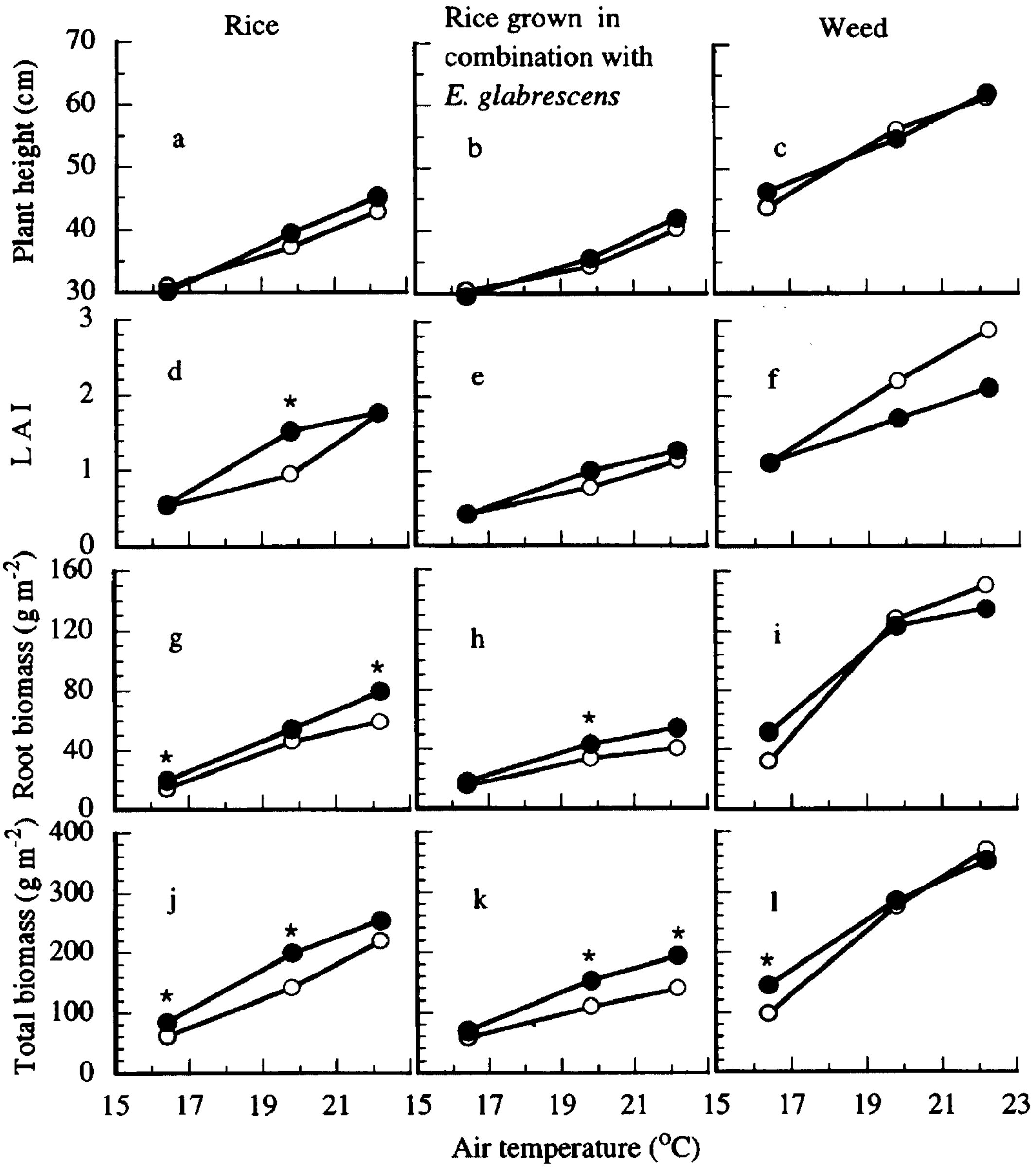

Fig. 3. Plant height(a-c), leaf area index(LAI, d-f), root(g-i) and total biomass(j-l) in rice, rice in combination with *E. glabrescens* and *E. glabrescens* exposed to ambient(open symbols) and elevated CO$_2$(closed symbols) as a function of air temperature. *indicates statistical significance of $p < 0.05$

increased under elevated CO$_2$ at moderate and high temperature (Fig. 3e). In contrast, elevated CO$_2$ led to decreases in LAI of *E. glabrescens*, and the magnitude of this effect was larger with increased temperatures (Fig. 3f). Nevertheless, in a similar study with the cultivar Akihikari, similiar responses in leaf area at early growth were demonstrated, indicating the competition for light (shading) between both species may be altered by elevated CO$_2$ (Kim et al., 1996b).

Elevated CO$_2$ increased rice root biomass from 16 to 41% over all mixtures and temperatures (Fig. 3g,h). However, the largest increase was observed at the higher temperature. Unlike rice, responses of root biomass in *E. glabrescens* to elevated CO_2 were greater at the lower temperatures than at higher temperatures. At high temperatures, elevated CO_2 reduced root biomass (Fig. 3i). Previous studies on rice also have shown that elevated CO_2 enhance root biomass and/or root to shoot ratio (Imai et al., 1985; Rogers et al., 1992; Ziska & Teramura, 1992; Kim et al., 1996b). Thus it appears that an increase in root biomass of rice, caused by elevated CO_2, also may affect its competitive ability for nutrients during early growth. Similiarly, a previous study has also found that for rice, elevated CO_2 resulted in increased nitrogen uptake during early growth (Kim, 1996a).

For all mixtures, elevated CO_2 significantly increased total rice biomass production (Fig. 3j,k). As with root biomass, the increases in total biomass resulting from elevated CO_2 varied from 16% to 40% with air temperature. Elevated CO_2 tended to increase root and total biomass production much more than any other growth parameter. Similar responses have been found in other studies (Imai et al., 1985; Baker et al., 1990). For *E. glabrescens*, the response of total biomass to elevated CO_2 and temperature was nearly paralled to the response of root biomass (Fig. 3l).

Figure 4 shows the decrease in LAI and total biomass of rice when grown with *E. glabrescens* as a function of air temperature. At the lowest temperature, the decrease in LAI and total biomass was significantly greater at elevated CO_2 than ambient CO_2; the magnitude of the decreases in LAI and total biomass were 18% and 3% respectively at ambient CO_2, and 24% and 18% respectively at elevated CO_2. However, at the highest temperature, the decreases in LAI and total biomass of rice grown at elevated CO_2 were significantly less than that of rice grown at ambient CO_2; the magnitude of decreases in LAI and total biomass were 32% and 36% respectively at ambient CO_2, and 28% and 22% respectively at elevated CO_2. These results indicate that under elevated CO_2, the competitive ability of rice is increased at higher temperatures but not at lower temperatures. In other words, this means that weeds originating from cool regions such as northern Japan, may grow better at lower temperature than rice at elevated CO_2. In Korea and Japan, when rice crops are established by direct seeding cultivation, seeds are generally sown when average air temperature

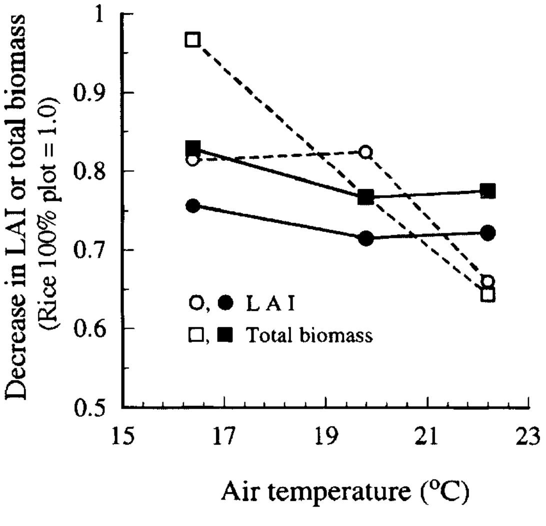

Fig. 4. Decrease in leaf area index(LAI) and total biomass of rice grown in combination with *E. glabrescens* as a fuction of air temperarure under ambient(open symbols) and elevated CO_2(closed symbols)

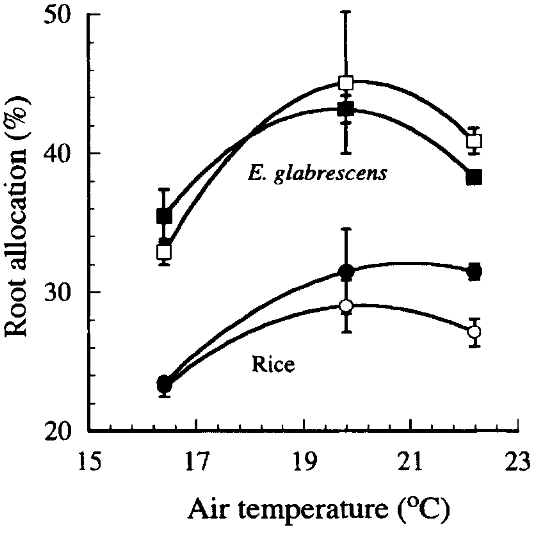

Fig. 5. Biomass allocated to the root(%) in rice and *E. glabrescens* exposed to ambient(open symbols) and elevated CO_2(closed symbols) as a function of air temperature. Verical bar indicates the standard erorr.

is below 20° C. Thus selection of rice genotypes which are likely to be more competitive under lower temperatures may be as important as selecting for growth under elevated CO_2 environments.

Biomass allocations to roots in rice and *E. glabrescens* grown at ambient and elevated CO_2 as a function of air temperature are shown in Figure 5. Elevated CO_2 increased root allocation in rice, particularly at the highest temperatrure. In contrast, at the highest temperature, root allocation in *E. glabrescens* grown at elevated CO_2, was less than at ambient CO_2, while elevated CO_2 increased allocation at the lowest temperature. From this result, we found that under elevated CO_2, the response of rice competitive ability (defined as the magnitude of the rice biomass decrease by *E. glabrescens*) to temperature, such as described previously in Figure 4, is depends strongly on the response of root allocation to temperature. In addition, it seems that elevated CO_2 preferentially distributed for biomass to roots in rice, prior to other the vegetative parts at modreate and high temperatures, and is likely to result in increased nitrogen uptake during early growth (Kim, 1996a).

In conclusion, at higher temperature, elevated CO_2 may enhance the competitive ability of direct seeded rice during early crop growth. However, at lower temperatures, the competitive ability of *E. glabrescens* seems to be greater. Consequently, selection of rice genotypes which are more competitive under lower temperatures and high CO_2 may be needed.

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