

ABSTRACT

In order to predict change in the geographical distribution of C3 and C4 plants resulting from elevated atmospheric temperature and CO₂, it is essential to characterize the effects of elevated temperature and CO₂ on the phenology, vegetative response, and reproductive output of populations under field-like conditions. To achieve this goal, two facilities, a Temperature Gradient Chamber (TGC) and a CO₂-Temperature Gradient Chamber (CTGC), were constructed in Tsukuba, Japan. Both chambers had the same slender shape: 30 m long, 3 m wide and 2.5 m high. Their performance was confirmed by a test in 1998 in which the projected global warming conditions in the near future were simulated; that is, dependent on a daily or seasonal change in ambient meteorological conditions, the air temperature at the air outlet was warmed 5°C higher than the ambient temperature (the annual mean was 14.3°C) with a precision of $\pm 0.2^\circ\text{C}$ (the annual means were 19.2°C in the TGC and 19.1°C in the CTGC, respectively), gradually increasing approximately 1°C every 5 m. In the CTGC, where the CO₂ concentrations were linearly increased from the air inlet to the outlet, the CO₂ concentrations of 0m, 10 m and 25 m in daytime were 372 (ambient), 537 (1.4x) and 756 ppm (2x), respectively. Moreover, the chambers' ability to control the air temperature and CO₂ concentration were excellent and their space allowed for direct measurements of leaf water potential, gas exchange, soil respiration etc. In the TGC we can investigate the effects of increasing temperatures and in the CTGC we can investigate global warming by seeing the compound effects of temperature and CO₂ enrichment.

In addition, the chambers developed here have a great advantage over other facilities such as Free-Air CO₂ Enrichment (FACE) and Open Top Chamber (OTC) systems. For example, the construction and maintenance costs

per unit area of the TGC and the CTGC are much lower than those of the FACE system. Although these facilities were designed for small-statured plants or vegetation such as grasses or tree sapling (< 2.5 m height), wide spaces compared with the OTC allowed to measure physiological and ecological responses in population level (e.g. photosynthesis, plant and soil respirations, leaf area index, and dry matter production and reproductive output per unit ground area etc.) to temperature rise and/or elevated CO₂ under the field environmental condition. Also, the TGC and the CTGC can simulate continuous gradient conditions, from the current to the predicted future conditions, so that plant responses to wide range of global warming can be measured. When used in conjunction with the CO₂ gradient chamber, these facilities allow both parameterization and validation data sets for models contributing to plant growth, species composition, and global carbon flux analysis to be obtained.

A growth experiment was conducted on a population level throughout a full growth season using the TGC and CTGC. Phenology, vegetative response, and the reproductive output of one annual C3 species population (*Chenopodium album*) and two annual C4 species populations (*Echinochloa crus-galli* and *Setaria viridis*) were measured. Three annuals were grown under ambient condition (Control plot), 2°C higher condition with ambient CO₂ (T2 plot), 4°C higher condition with ambient CO₂ (T4 plot), 2°C higher condition with 1.4 fold CO₂ concentration of ambient (CT2 plot), and 4°C higher condition with 1.8 fold CO₂ concentration of ambient (CT4 plot). The most critical effect of global warming was given by thermal environment. The day with a daily mean temperature over 5°C were 282, 311, and 350 days in the Control, 2°C higher condition, and 4°C higher condition, respectively. The periods available for plant

growth resulted from elongated growing season. Therefore, warming would contribute to an increase in the annual production of dry matter per unit area per year, since the growth period would surely be elongated. Phenologies for all plants were advanced with increasing temperature. As a result, in temperature-elevated plots, mean air temperature during vegetative stage did not increase. During the vegetative stage for all species mean air temperature decreased in elevated temperature plots rather than the Control plot.

The high growth ability of the C3 plant population, *C. album*, was sustained under the low temperature condition due to the shifted phenology. The effect of elevated CO₂ did not fully stimulate the growth of *C. album* population during the vegetative stage because the effect of CO₂ on growth was dependent on temperature. However, the *C. album* population in the T2 and T4 plots showed the large decrease of growth rate with increasing temperature. The elevated CO₂ would fully compensate for the negative effect of high temperature on plant growth. As a result, the productivity and the reproductive output of C3 species were greatly increased by elevated CO₂. In the CT4 plot, the total final dry weight per unit ground area of *C. album* population was significantly increased by about two folds (97.6%) compared with plants in the T4 plot. Also, *C. album* population grown in the T2 plot showed significant decrease in total final dry weight per unit ground area compared with that of the CT2 plot. The seed productivity of *C. album* also increased by 15.9% and 114.4% in the CT2 and CT4 plots, respectively, as compared to the Control plot. With this advantage, *C. album* constructed a stand structure composed with various sizes, which can allow for efficient acquirement of resources such as light. The *C. album* population also showed a high leaf area index (LAI), net assimilation rate

(*NAR*), and relative growth rate (*RGR*) in elevated CO₂ plots. Consequently, increase in productivity of dry matter and seed productions in elevated CO₂ resulted from high *LAI*, *NAR*, and *RGR*.

On the other hand, the mean air temperature during the vegetative stage for the C4 plant, in particular the *E. crus-galli* population, showed significantly lower decrease in elevated temperature plots than in the Control plot. As a result, C4 plant populations showed a negative response to elevated temperature in dry matter production and in reproductive output. Although the decrease of productivity for C4 plants would be compensated by elevated CO₂, the potential effect would be small in comparison with the C3 species.

On the basis of this study, C3 species may be more favored by elevated CO₂. Simultaneous increase in temperature and CO₂ may result in a competitive advantage for C3 species relative to C4 species which do not increase dry matter production and reproductive output. Under elevated temperature and atmospheric CO₂, C3 species would be the most likely species to show significant increases in population size, as a result of increased total dry matter production and reproductive output, and would consequently expand their area. The overall trend of increasing dry matter and seed production for the C3 plant with increasing temperature and CO₂ indicates that the distribution and abundance of future C3 populations in a hotter and higher CO₂ world is likely to change.

Key words;

CO₂ enrichment, Emergence time and flowering time, Field-like conditions,

Global warming, Plant phenology, Reproductive output, Solar radiation,
Temperature Gradient Chamber and CO₂-Temperature Gradient Chamber, Total
dry weight, Population