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Research Article

An Open Top Chamber for Forage Maize to Study the Effect of Elevated Temperature by Global Warming

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ABSTRACT

The increase in temperature due to climate warming is predicted to affect crop yields in the future. Until now, various types of OTC (open top chamber) that simulate the future climate condition have been developed and used to study the effect of temperature increase due to global warming on maize growth. However, in most OTCs, high equipment and maintenance costs were required to artificially increase the temperature. This study was carried to develop a cost-effective and simple OTC suitable for climate warming experiments for forage maize. Three octagonal OTCs with a height of 3.5 m × a diameter of 4.08 m and a partially covered top were constructed. The lower part of OTC covered film was opened at a height of 26 cm (OTC-26), 12 cm (OTC-12) from the ground surface, or not opened (0 cm, OTC-0). Mean air temperatures during the daytime on a sunny day in OTC-0, OTC-12 and OTC-26 increased to 3.23℃, 1.33℃, and 0.89℃, respectively, compared to the ambient control plot. For a pilot test, forage maize, ‘Gwangpyeongok’ was grown at OTCs and ambient control plots. As a result, in the late maize vegetative growth phase (July 30), the plant height was increased more than 45% higher than the ambient control plot in all OTC plots, and the stem diameter also increased in all OTC plots. These results indicate that it is possible to set the temperature inside the OTC by adjusting the opening height of the lower end of the OTC, and it can be applied to study the response of forage maize to elevated temperature. An OTC, with its advantages of energy free, low maintenance cost, and simple temperature setting, will be helpful in studying maize growth responsiveness to climate warming in the future.

(Key words: Climate warming, Forage maize, Open-top chamber, Temperature)

Ⅰ. INTRODUCTION

The increase in greenhouse gas concentrations due to human activities since the industrial age increases the radiative heating, leading to an increase in global temperature (Shindell and Faluvegi, 2009). The rate of temperature increase on the earth's surface has been accelerated more than ever, and the average 10-year surface temperature over the past 30 years has been warmer than any previous year (IPCC, 2013). The intergovernmental panel on climate change (IPCC) has published a scenario of representative concentration pathways (RCP) that predicts future changes in CO_2 concentration values depending on whether greenhouse gas reduction policies are implemented (IPCC, 2014). According to the IPCC, in the case of the RCP 8.5 scenario in which no efforts are made to reduce greenhouse gases, the earth's surface temperature is expected to increase by 2.6-4.8°C in the second half of the 21st century (IPCC 2014). Environmental stress caused by climate change is the main cause of crop yield decline (Hatfield et al., 2017). One of them, high temperature, has various effects on the growth, development and productivity of crops (Hall, 2001). According to the simulation analysis of crop growth model based on the RCP8.5 scenario, it was reported that the major summer crops, rice, potatoes, maize are expected to decrease by 25%, 30%, and 10-20%, respectively (Lee et al., 2017).

Maize cultivation is mechanized from sowing to harvest, and is a representative forage crop grown in summer because of its high yield per unit area and high total digestible nutrient (TDN) (Son et al., 2009). Studies on the response of maize to high temperature stress caused by global warming have been mainly analyzed for grain yield. The most sensitive stage to high temperature among the growth stages of maize is known as the pollination stage, and pollen viability is known to decrease when exposed to temperatures above 35°C (Herrero

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and Johnson, 1980; Shim et al, 2017). Exposure of kernels to high temperature reduced grain yield of maize (Commuri and Jones, 2001). On the other hand, since forage maize uses the entire above-ground biomass as feed, it is necessary to study the temperature response throughout the vegetative and reproductive phases.

Although a controlled environment chamber has been used to study the response to such climate warming, it is useful to elucidate the detailed mechanism under specific conditions, but it is difficult to predict the response in the actual field cultivation environment through the results (Ordóñez et al., 2015). Open top chamber (OTC) has been widely used for field testing that compensates for these disadvantages, and it has been widely used for research on effects of changes in temperature or CO_2 concentration by applying it to grasslands or crop fields in various climatic zones (Flanagan et al., 2013; Buhrmann et al., 2016). Several methods of increasing temperature to simulate climate warming have been reported. In addition to natural temperature increasing techniques such as green house or OTC, there are soil heating methods using electric heating cables (Schindlbacher et al. 2009) and methods using infrared radiation (Morin et al. 2010). However, these methods require electrical energy, which limits the installation location, and requires high maintenance costs (Sun et al., 2013).

Therefore, this study was carried out to develop an OTC suitable for the experiment of growth response of forage maize, which does not require energy to study climate warming response, has low installation and maintenance costs, and can set different temperature regimes easy.

Ⅱ. MATERIALS AND METHODS

1. Open top chamber and experimental design

The experimental site was at Gyeongsang National University Affiliated Animal Farm (128°14' East longitude, 35°20' North latitude) in Jinju, Gyeongsangnam-do’ Korea. OTC designs described by Meng et al. (2014) and Welshofer et al. (2018) were partially modified. Three octagonal OTCs with a height of 3.5 m × a diameter of 4.08 m and a partially covered top were constructed (Fig. 1). As the cover material, a polyolefin

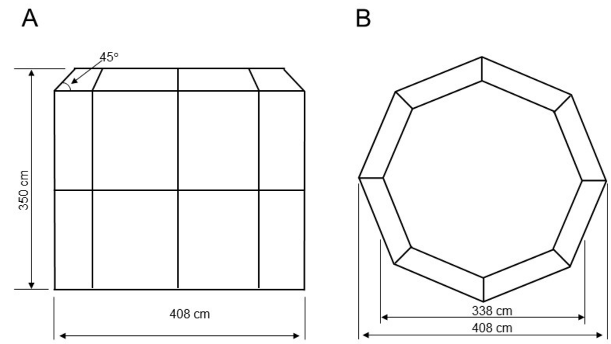

Fig. 1. Structure of open top chamber. Side view (A) and top view (B).

film (Clean alpha 21, Sumitomo Chemical Company, Limited, Tokyo, Japan) with high light transmittance (90%) was fixed to an iron frame. To set the degree of natural air circulation inside the OTC to different levels, the bottom of each OTC's plastic film sheet was opened at different heights. That is, the bottom of the sheet was cut from the ground surface to 0 cm (OTC-0, unopened), 12 cm (OTC-12) and 26 cm (OTC-26), respectively.

2. Climatic data measurement

From June 5, 2020 to September 23, 2020, a data logger (Watchdog 1000 series, Spectrum technologies, lnc., USA) was installed to measure climate data for ambient control and OTC plots. The data logger was installed at a height of 1.5 m from the ground surface and measured the temperature and relative humidity every 30 minutes.

3. Cultivation of forage maize

Gwangpyeongok, a forage maize variety, was used for the growth test. Maize seeds were sown on Jun 15, 2020. In each OTC, 3 rows of 1 m in length were sown at 15 cm intervals, and the rows were 75 cm apart. As a control, an ambient plot was created outside the OTC and seeded in the same way. Chemical fertilizers were applied in different doses of nitrogen (200 kg ha^{-1}), phosphorus (150 kg ha^{-1}) and potassium contents (150 kg ha^{-1}). Approximately 50% nitrogen was applied on the sowing date, 50% at knee-high stage. Phosphorus and potassium were considered as the basis of fertilizer. Experimental data collection was observed by selecting an object in the middle row. Maize growth and development stages were determined

Table 1. Changes of mean air temperatures in ambient control and OTC plots during representative growth stages of forage maize

Period (growth stage)	Temperature regimes in OTCs	Mean temperature (℃)	Maximum temperature (℃)	Minimum temperature (℃)
Sunny day of Jun 30 to Jul 2 (Vegetative stage)	Ambient	22.60±0.53[b]	29.7	16.7
	OTC-26	23.49±0.29[b]	32.8	16.9
	OTC-12	23.93±0.26[b]	33.9	17.3
	OTC-0	25.83±1.21[a]	40.4	17.1
Cloudy day of Aug 3 to 5 (Anthesis stage)	Ambient	27.21±0.19[b]	31.2	23.2
	OTC-26	27.65±0.63[ab]	35.5	23.2
	OTC-12	28.27±0.73[ab]	36.9	23.3
	OTC-0	28.49±0.67[a]	36.7	23.5

Values in third column represent means ±SD
[a,b]Means with the same letter in a row for a growth stage are not differed significantly (p<0.05)

according to the method of Bell (2017). In the case of the vegetative growth phase, each growth stage was determined by measuring the number of leaves that appeared completely.

4. Statistical analysis

For statistical analysis, one-way ANOVA was performed using IBM SPSS statistics (IBM SPSS Statistics for Windows, Version 25.0. Armonk, NY, USA), and the post-hoc test was

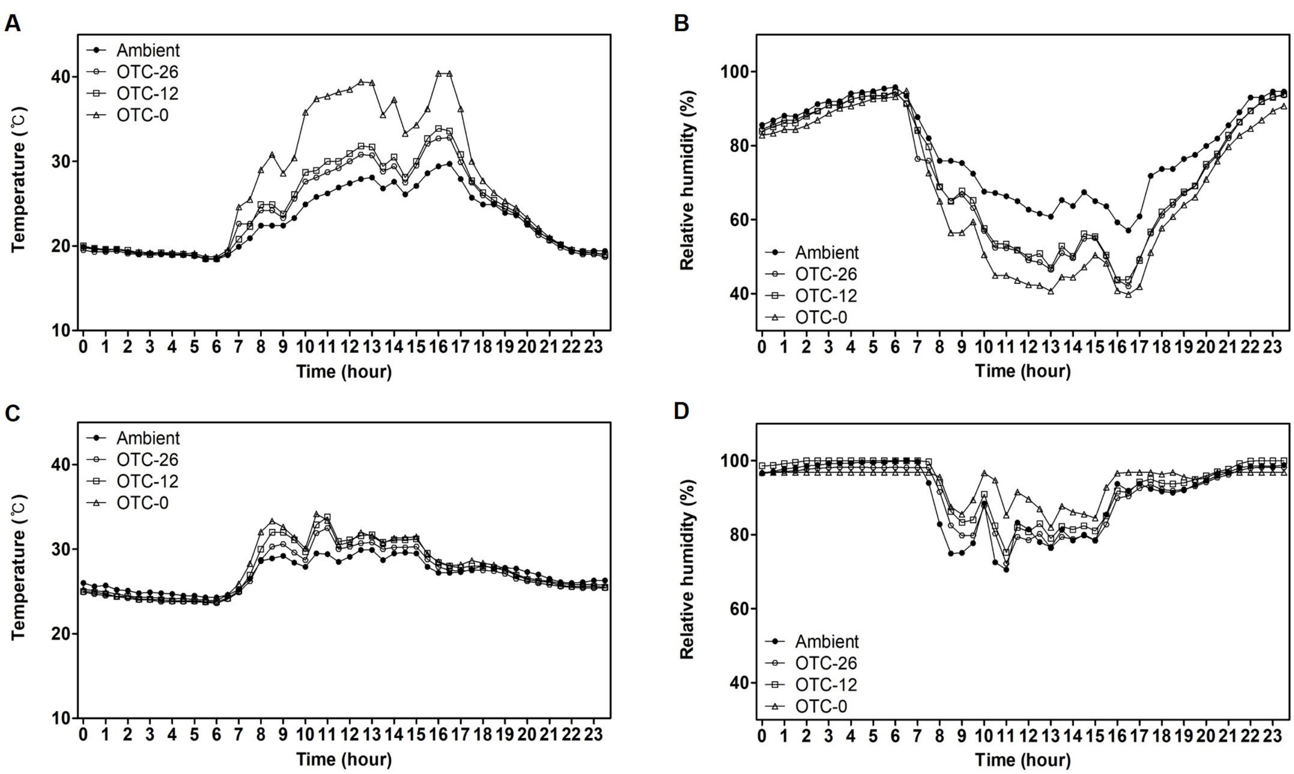

Fig. 2. Diurnal variation in air temperature (A, C) and relative humidity (B, D) in ambient control and OTC plots. A and B, a sunny day (July 1, 100,000–130,000 lux) in vegetative stage; C and D, a cloudy day (Aug 5, 79,000~95,000 lux) in anthesis stage.

performed using Duncan's multiple range test method. Significance tests were performed at the 5% level.

Ⅲ. RESULTS AND DISCUSSION

1. Changes in temperature and humidity in OTC

The air temperature and relative humidity of the OTC inside and ambient control plots for one day were compared on a sunny day (100,000-130,000 lux) in the vegetative stage or a cloudy day (79,000~95,000 lux) in the anthesis stage, which is a typical growth stage of maize (Fig. 2).

In the case of the daytime air temperature on a sunny day (July 1), the temperature inside the OTC starts to show different temperature increases depending on the degree of opening of the lower part of the OTC from 07:00 to 19:00 (Fig. 2). During the nighttime, there was a smaller difference compared to the daytime. The change in relative humidity also showed a similar tendency to the change in air temperature. On a cloudy day (Aug 5), the change in air temperature and humidity during the daytime increased less than on a sunny day.

Changes of mean air temperatures in ambient control and OTC plots during representative growth stages of forage maize were measured. The mean air temperature and the maximum and minimum air temperatures of 3 days on a sunny day (Jun 30 - July 2, vegetative stage) or 3 days on a cloudy day (Aug 3-5) were compared (Table 1). In sunny days, according to the degree of opening of the lower part of the OTC, the mean air temperature of the closed OTC (OTC-0) was 25.83±1.21℃, which was about 3.23℃ higher than the 22.60±0.53℃ of the ambient control plot. The air temperature of OTC-12 was 23.93±0.26℃, which was increased by 1.33℃ more than the ambient control plot, and the mean air temperature of the OTC-26 was 23.49±0.29℃, which was 0.89℃ higher than that of the ambient control plot (Table 1). It was observed that the relative humidity of OTC decreased as the temperature increased. In the case of the mean air temperature of 3 days (Aug 3-5, anthesis stage) on a typical cloudy day, the closed OTC (OTC-0) was 28.49±0.67℃, which was 1.28℃ higher than the 27.21±0.19℃ of the ambient control plot, and the most open OTC-26 was 27.65±0.63℃, which was 0.44℃ higher than that of the ambient control plot, respectively. These results suggest that the difference in OTC internal air temperature varies greatly depending on the presence or absence of sunlight, and that there may also be differences depending on the seasons when the angle of incidence of sunlight changes. Buhrmann et al. (2016) also reported that the increase in mean daytime temperature tends to decrease from summer to autumn. Therefore, these results indicate that the temperature inside the OTC can be controlled and maintained by the opening the lower end of the OTC with different height.

2. Forage maize growth in OTC at different temperatures

We investigated the effect of OTC set at different air temperatures on the growth of forage maize. At the end of the vegetative growth stage (July 30), 56 days after sowing, the plant height of forage maize was higher in all OTCs with increased air temperature than that of the ambient control plot (Fig. 3). OTC-26, which showed the smallest increase in temperature compared to the ambient control plot, showed the highest increase in plant height, which was 63% higher than that of the ambient control plot, and in the case of OTC-0, which showed the highest temperature increase, the increase in plant height was smaller. Also, in the growth stage after the anthesis stage (Aug 5), all OTCs showed higher plant height than the ambient control plot. In maturity stage (Sep 19), similar results were observed but the OTC-12 showed a slight decrease compared to other OTCs.

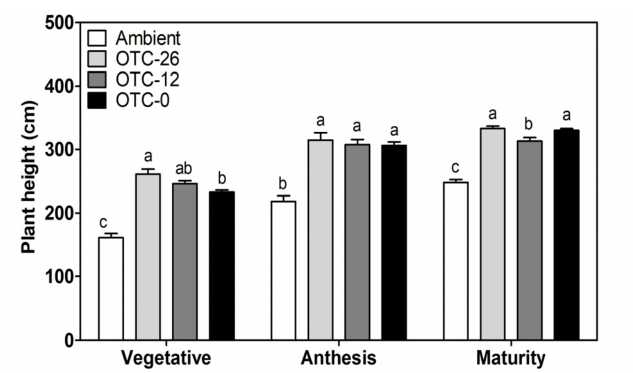

Fig. 3. Changes in plant height of forage maize at different growth stage grown in ambient and OTC plots. Plant height was measured at July 30 for vegetative stage, August 5 for anthesis stage and Sep 19, 2020 for maturity stage, respectively.

On the other hand, as a result of comparing the diameter

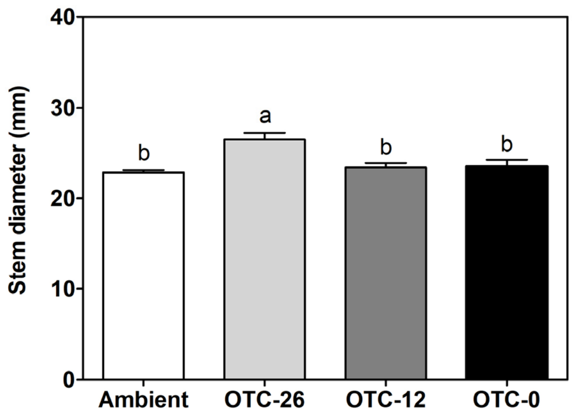

Fig. 4. Stem diameter of forage maize at harvesting stage grown in ambient control and OTC plots.

of the stems at the harvest stage of forage maize, the OTC-26 with the lowest temperature increase showed the largest increase compared to the ambient control, and other OTCs showed no difference from the ambient control plot (Fig. 4). These results indicate that different OTC air temperatures have an effect on the vegetative growth stage of forage maize, and that the degree of influence for each growth stage may be different. Until now, it has been reported that high temperature mainly affects the formation of grains in maize and reduces yield (Lizaso et al, 2018; Wang et al., 2020). In this study, it was confirmed that high temperature also affects the vegetative growth stage of forage maize. Therefore, it means that the temperature increase due to climate warming probably also affects the productivity of stem and foliage of forage maize.

Through this experiment, it was possible to develop an OTC capable of treating different levels of temperature increase during the growing period of maize, and it was confirmed that the pilot test affects the growth of forage maize at different levels. Therefore, it shows that by adjusting the opening height of the lower end of the OTC, it is possible to efficiently simulate the cultivation environment with different degrees of climate warming at low cost and low maintenance cost. It will be helpful to systematically study the response of maize to climate warming.

Ⅳ. CONCLUSION

An OTC capable of setting different temperatures for climate warming experiments of forage maize, a tall forage crop, was constructed. As a result of different heights of separation from the ground surface at the bottom of the OTC, it was possible to develop an OTC whose mean air temperature was increased from 0.86°C to 3.1°C than that of the ambient control plot. As a result of cultivating forage maize in a pilot experiment at OTC at different temperatures, the plant height of maize at each growth stage was different, and the size of the stem diameter at the harvest stage was also affected. These results indicate that it is possible to increase the temperature inside the OTC even by adjusting the degree of natural air circulation through the adjustment of the opening height of the lower part of the OTC. The low-cost, low-maintenance, and easy-to-set temperature OTC for maize developed in this experiment will be helpful in studying detailed changes in maize growth and productivity response to future climate warming.

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