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The CO_2 Concentration Variation During CO_2 Enrichment in Greenhouse and the Effect of CO_2 Enrichment on Plant Growth

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***Abstract*— Carbon dioxide (CO_2) plays important roles in crop growth and yield. In this study, we showed the variation of CO_2 concentration in greenhouses during CO_2enrichment and the effects of CO_2enrichment on growth of *Alstroemeria* 'Hanhera'. The plants were grown in CO_2 enrichment greenhouse and non- CO_2 enrichment greenhouse. CO_2 supplement time was performed differently for each term (The first term : 05:30~18:00 with twice rest. the second term : 05:30~16:00 with once rest. the third term : 05:30~12:30). The daily CO_2 concentration changed depending on plant growth and greenhouse management, but the CO_2 concentration in CO_2 enrichment greenhouse maintained approximately 640 ppm from 6:00 to 10:00. It was reported that CO_2 enrichment significantly increased the yield, shoot length and total number of flowers. Also, there was increase in stem thickness. These results suggest that CO_2 enrichment had positive impacts on *Alstroemeria*, which would be aimed at experiments with bigger scale and more details in future.**

Keywords*— CO_2 enrichment; CO_2 supplement; CO_2 generator; Horticulture; Photosynthesis;

I. INTRODUCTION

Carbon dioxide (CO_2) is one of the most important factors for plant growth. CO_2 concentration management is dispensable for horticultural plants. CO_2 concentration in a greenhouse decreases rapidly after sunrise due to the photosynthesis, but ventilation cannot be implemented anytime to maintain the greenhouse condition such as temperature [1]. It causes the inhibition of plant growth, so growers try to overcome this problem. Many studies have been researched that most plants take advantage of additional CO_2 supplement which is called " CO_2 enrichment" or " CO_2 fertilization" [2]. The benefit of CO_2 enrichment is obvious. Pot plants, cut flowers, vegetables and forest plants show very positive effects from CO_2 enrichment by increased dry weight, plant height, number of leaves and lateral branching [2]. For example, Numerous studies have reported that CO_2 enrichment promotes yield and quality in flowers [3-4]. CO_2 enrichment at 800 ppm for 'Sagahonoka' was effective in increasing the photosynthetic rate and distribution of photoassimilates to fruits, and the yields of strawberries [5]. Similarly, it is reported that CO_2 enrichment on tomato increases net photosynthetic rate, single fruit weight and yield per plant [6].

Growers have to consider how to increase CO_2 concentration in a greenhouse to improve crop yield and quality. There are several methods to additional CO2 supplement (Table 1) : Solid CO_2, Liquid CO_2, Fuel-burn type CO_2 generator. Farmers in South Korea usually use a fuel-burn type CO_2 generator by combustion of hydrocarbon fuels such as kerosene and propane. It is reported that the effect of CO_2 enrichment for strawberry 'Seolhyang' using a fuel-burn type CO_2 generator [7]. However, most fuel-burn type CO_2 generators emit harmful gases such as CO and NO_X [8]. These harmful gases lead to oxidative damage and degrades photosynthesis in plants [9]. Besides, heat is generated inevitably and it is so high that plants suffer heat damage (Fig. 1). To overcome these problems, a catalyst-type CO_2 generator which can oxidize propane to CO_2 was developed (Fig. 2.).

Fig. 1. The damage of leaves from high temperature of emission gas by fuel-burn type CO_2 generators.

Fig. 2. The catalyst-type CO_2 generators.

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TABLE I. THE METHOD OF CO_2 SUPPLEMENT

Type	Characteristic
Solid CO_2	- Pure CO_2 supplement - Annoying installation and maintenance
Liquid CO_2	- Pure CO_2 supplement - Expensive installation and maintenance fee - Unstable supplement
Fuel-burn type CO_2 generator	- Expensive installation and maintenance fee - Concern about damage from harmful emission gas

Alstroemeria is popular as a cut flower crop due to low energy growing requirement and high productivity. Even though *Alstroemeria* is cultivated in South Korea recently, and Korean *Alstroemeria* varieties such as 'Hanhera' and 'Hanapollon' are developed, responses to CO_2 enrichment for Korean *Alstroemeria* varieties in South Korea weather have not been elaborately researched.

The objectives of this study are to: (1) analyze the variation of atmosphere in CO_2 enrichment greenhouse (ECO2-G) and Non- CO_2 enrichment greenhouse (NCO2-G) during cultivation period with CO2 enrichment using a catalyst-type CO_2 generator (CO2-Gen), (2) investigate the influence of CO_2 enrichment on *Alstroemeria* 'Hanhera'

II. MATERIAL AND METHOD

A. *Plant Materials and Growth Conditions.*

The experiment was conducted at Chonnam University, Gwangju, South Korea (35° 09' 35'' N, 126° 51' 11" E) from 12.03.2021 to 05.20.2022. To conduct the experiment, two identical greenhouses were used. Each greenhouse had the same dimension (Area : 98 m^2, Hight : 3 m) and a ridge (110 cm). Twenty-one *Alstroemeria* 'Hanhera' pruned leaving 10 cm shoot part were planted with 20 cm intervals apart (Row : 3, Column : 7) on soil (Fig. 3). A first cut net (1.2 m × 10 m) was set at 30 cm height on 09.14.2021 and a second cut net (1.2 m × 10 m) was set at 80 cm height on 10.22.2021. These plants were drip-irrigated for 5~7 minutes with plain tap water twice weekly manually.

Fig. 3. *Alstroemeria* 'Hanhera' after transplatation.

In order to prevent the plant from freezing, inner-greenhouses were installed additionally (Fig. 4, Yellow arrow) and a ceramic electric heater (Chansung boiler, South Korea) was operated for 15 °C. The inner-greenhouses was opened at approximately 9 o'clock manually and the windows of greenhouses was opened automatically when the temperature of greenhouse was above 20 °C (Fig. 4, Red arrow).

B. *CO_2 enrichment*

For supplement CO_2 enrichment on ECO2-G, a CO2-Gen (DAONiA, DAONRS Inc., South Korea) was set (Fig. 4, Green arrow). The CO2-Gen generated 0.36 kg/h CO_2. There were totally 3 terms depending on operating method of CO2-Gen (Table 2). At the first term, CO2-Gen was operated 5:30 ~ 18:00 with twice rest time. Sunset time and the characteristic were not considered at this term. At the second term, CO2-Gen was operated 5:30 ~ 16:00 with once rest time depending on Sunset time (Sunset time on December was approximately 17:30). Finally, at the third term, CO2-Gen was operated 5:30 ~ 12:00 based on previous data (CO_2 concentration kept low after opening the inner-greenhouse and windows of greenhouses).

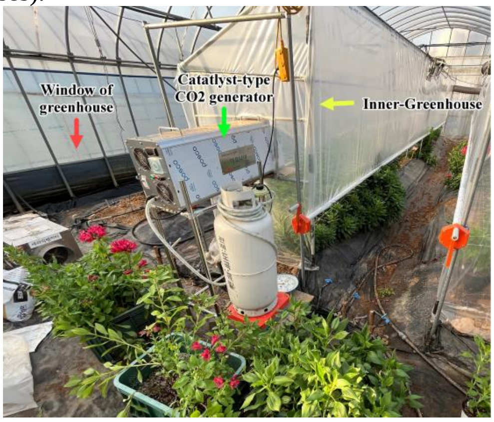

Fig. 4. Set up the ECO2-G. The red arrow points at the window of the greenhouse; The yellow arrow points at the inner-greenhouse; The green arrow points at the catalyst-type CO_2 generator.

TABLE II. THE SCHEDULE OF CO2-GEN

Term	Time	
	Work	Rest
The first term 12.04.2021 ~ 12.14.2021	5:30 ~ 9:00 9:15 ~ 12:30 12:45 ~ 18:00	9:00 ~ 09:15 12:30 ~ 12:45
The second term[a)] 12.15.2021 ~ 01.10.2022 01.18.2022 ~ 01.23.2022	5:30 ~ 12:30 12:45 ~ 16:00	12:30 ~ 12:45
The third term 01.24.2022 ~ 02.28.2022	5:30 ~ 12:30	-

[a)] Repair the CO2-Gen on 01. 11. 2011 ~ 01.17. 2022

C. *Data measurements and stores*

The temperature of each greenhouse was measured by a temperature sensor (PT100 RTD, DEAJIN SENSOR ELECTRIC WORKS, South Korea) and CO_2 concentration of each greenhouse was measured by CO_2 sensor (CM1107, CUBIC, China). A data acquisition system (DAONi-con, DAONRS Inc., South Korea) stored these data every 1 minutes.

D. Growth condition and yield analysis

Plant growth was investigated twice a week from the 126th (the first flowering day after the CO_2 enrichment) to the 144th day. The shoot thickness was measured under inflorescence and the shoot length was measured between ground and shoot apex. Flowers were counted when anther dehiscence began. The yield of cut flowers was investigated for every cut flower which was valuable as a product.and the shoot length was measured between ground and shoot apex. Flowers were counted when anther dehiscence began. The yield of cut flowers was investigated for every cut flower which was valuable as a product.

E. Statistical analysis

Data was analyzed using Excel (Version 16, Microsoft 365, USA) and was presented as 5% trimmed mean.

III. RESULT AND DISCUSSION

A. The variation of CO_2 concentration in greenhouse

CO_2 concentration data in greenhouses were presented every 10 minutes without noises (Fig. 5). Every graph shows that CO_2 concentration of ECO2-G increased immediately after CO_2 enrichment started and then decreased rapidly after opening the inner-greenhouse (Fig. 5, Red arrow). Although CO2-Gen was regenerator after 15 minutes rest, CO_2 concentration didn't increase at all from the window opened, whereas CO_2 concentration began to increase after the window closed. Especially, the extreme peak at the first term was observed higher than other terms after the window closed. It was expected because CO_2 was supplied longer and the consumption of CO_2 was not enough since the plants were not fully grown.

Considering ventilation to maintain the temperature of greenhouses, the effect of CO_2 enrichment may be enhanced strongly between 6 and 10 (Fig. 5) when the CO_2 concentration maintained high relatively. In the relevant section, it was shown that the total average CO_2 concentration of the ECO2-G was 644.68 ppm and the average CO_2 concentration of the NCO2-G was 391.06 ppm, which was approximately 250 ppm higher in the ECO2-G (Table 3).

TABLE III. THE AVERAGE OF CO_2 CONCENTRATION FROM 6:00 ~ 10:00 ON THE FIRST HALF, THE SECOND HALF AND WHOLE TIME

Time	ECO2 - G (ppm)	NCO2 - G (ppm)
Whole time (12.04.2021 ~ 01.10.2022, 01.18.2022 ~ 02.28.2022)	644.68	391.06
The first half (12.04.2021 ~ 01.10.2022)	694.36	418.54
The second half (01.18.2022 ~ 02.28.2022)	654.73	373.78

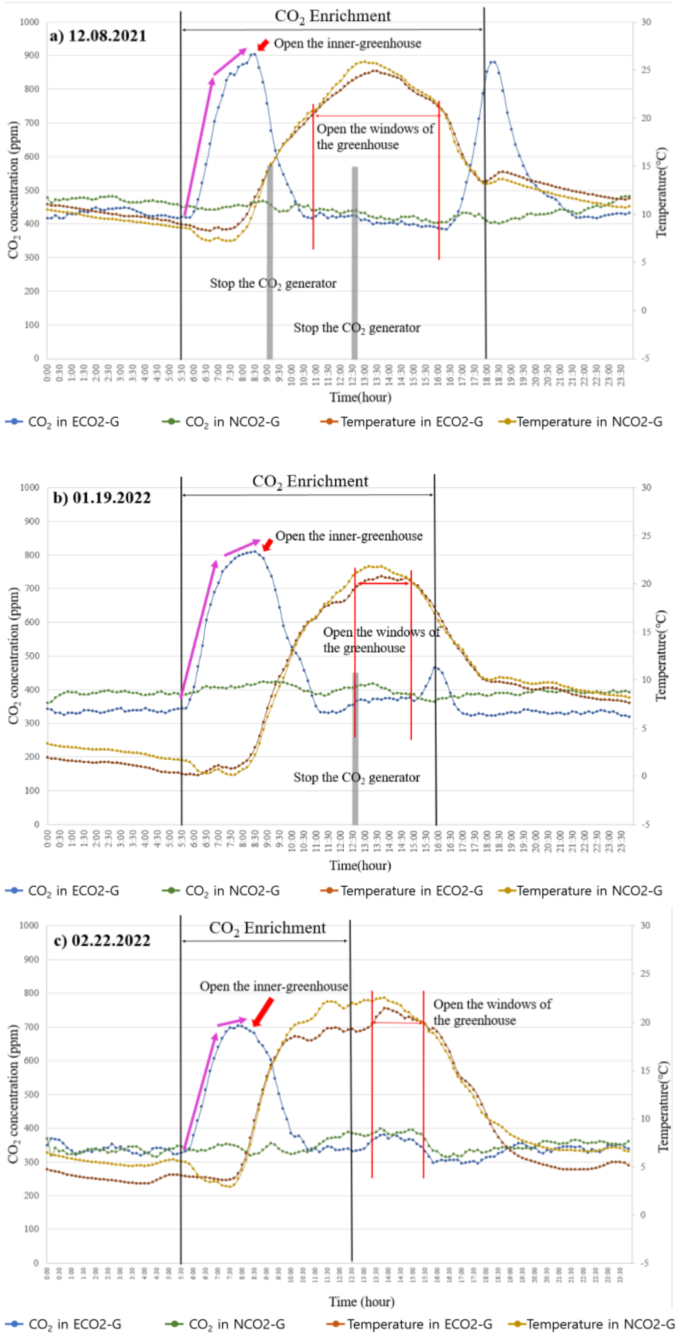

Fig. 5. The graphs of daily CO_2 concentration and temperature in ECO2-G and NCO2-G. The data is marked every 10 min. The violet arrow expresses the gradient line on increase time from 5:30 to 9:00. a) Data on 12.08. 2021. This data represents 'The first term' data. b) Data on 01.19. 2022. This data represents 'The second term' data. c) Data on 02.22. 2022. This data represents 'The third term' data.

After the start of CO_2 enrichment, the CO_2 concentration increased section (Figure 5, violet arrow) was enlarged to show a trend line (Fig. 6). The CO_2 concentration decreased as the term passed (Fig. 6). The average of CO_2 concentration from 6 to 10 in ECO2-G was analyzed dividing the experiment into the first half (12.04.2021 to 01.10.2022) and the second half (01.18.2022 to 02.28.2022) (Table 3). In the first half, the average concentration of CO_2 in ECO2-G was 694.36 ppm and 418.54 in NCO2-G. In the second half, the average concentration of CO_2 in ECO2-G was 654.73 ppm and 373.78 ppm in NCO2-G, which decreased by approximately 40 ppm in both greenhouses. These results are analyzed to have decreased CO_2 concentration in the greenhouses as CO_2 consumption increased as plants gradually grew.

Interestingly, the change in CO_2 concentration between 6 and 9 o'clock changed the slope sharply before and after the particular points P_1, P_2, and P_3 (Fig. 6). Considering that these points were near sunrise time, it may be that the amount of CO_2 consumption increased as the photosynthesis activity began. The fact that the slope does not perfectly match the sunrise time is expected to be due to differences in the optical environment because of local weather differences. In addition, it is analyzed that the gradient decreased toward the second half of the experiment due to the increase relatively in CO_2 consumption as plants grew.

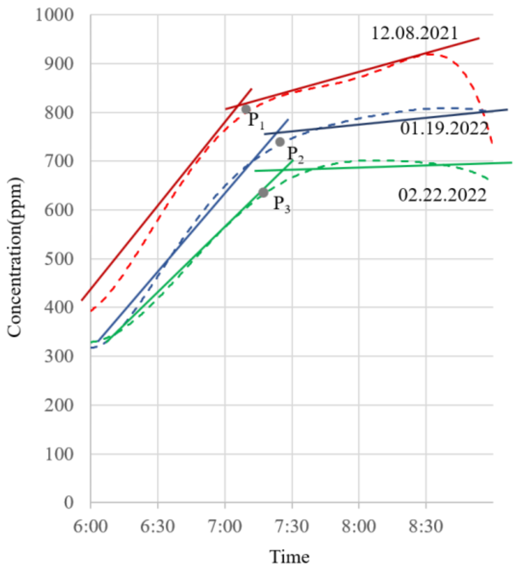

Fig. 6. The trend line of CO_2 concentration increase in ECO2-G between 6 and 9. Point P_1, P_2, P_3 are expressed the change points of gradient line.

CO_2 concentration in greenhouses can vary depending on greenhouse management, plant growth and weather. Therefore, it is necessary to efficient CO_2 supplement considering sunrise time and ventilation.

B. Plant growht and yield analysis

There was a dramatic difference visibly in ECO2-G and NCO2-G (Fig. 7). The total yield of ECO2-G was 515, which was approximately 62% higher than that of NCO2-G (Table 4). Also, the number of flowers per flowering shoot was 1.3 times higher for ECO2-G plants than NCO2-G plants (Table 4). Even though the shoot thickness was not strongly affected by CO_2 enrichment, CO_2 enrichment significantly improved shoot length with increase of 82%. This result may affect profits of farmers since the longer the length, the higher the product value.

TABLE IV. PLANT GROWTH IN *ALSTROEMERIA* 'HANHERA'

CO_2	**Total yield**	**Shoot length (cm)**	**Shoot thickness (mm)**	**The number of flowers per flowering shoot**
Control	317	65.05	6.00	11.92
Enrichment	515	111.62	6.74	16.03

Similar to our results, CO2 enrichment enhanced not only the quantities but also leaf net photosynthetic rate of Gerbera jamesonii [10]. Also, flowering-time was accelerated in high CO2 concentration environment [11-12] Similarly, CO2 enrichment had positive ef-fects on the cultivation of horticultural crops [13].

Plant growth is closely related to other factors such as temperature and light [14]. It was shown that the use of combined supplementary lighting and CO2 enrichment condi-tions for the commercial production of rose cultivars results in more advantages than when using supplementary lighting alone [15]. Combined high temperature and CO2 en-richment results in an increase in the proportion of small fruits depending on plants [16]. Therefore, it is necessary to optimize the CO2 enrichment management with other factors depending on crops for stable crop production.

IV. CONCLUSION

According to the results, we found that CO_2 concentration in greenhouses with plants are changeable by plant growth level and the amount of photosynthesis activity. And CO_2 enrichment has positive effect on *Alstroemeria* 'Hanhera'. Consequently, efficient CO_2 enrichment is able to increase the commercial profits by improving yield and plant growth.

In future study, it is necessary to maintain CO2 concentration in greenhouse during CO2 enrichment and investigate more details such as photosynthesis rate.

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