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Assessment of the Effect of Dimethyl Ether (DME) Combustion on Lettuce and Chinese Cabbage Growth in Greenhouse

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Abstract. The experiment was conducted to determine the performance of DME combustion gas when used as a fuel for DME burner for raising temperature and CO_2 concentration in greenhouse and also to examine its effects on chlorophyll content, and fresh and dry weight of lettuce and Chinese cabbage. DME-1 and DME-2 treatments consisted of average DME flow quantity in duct were 17.4 $m^3\ min^{-1}$ and 10.2 $m^3\ min^{-1}$ respectively to greenhouse-1 and greenhouse-2 and no DME gas was supplied to greenhouse-3 which was left as control (DME-3). DME supply times were 0.5 hr day^{-1}, 1 hr day^{-1}, 1:30 hrs day^{-1} and 2 hrs day^{-1} on week 1, 2, 3, and 4 respectively. Chlorophyll content and fresh and dry weight of lettuce and Chinese cabbage were measured for each treatment and analyzed through analysis of variance with a significance level of $P<0.05$. The result of the study showed that CO_2 concentration increased up to 265% and 174% and the level of temperature elevated 4.8°C and 3.1°C in greenhouse-1 and 2, respectively as compared to greenhouse-3 due to application of DME combustion gas. Although, the same crop management practices were provided in greenhouse-1, 2 and 3 at a same rate, the highest change ($p<0.05$) of chlorophyll content, fresh weight and dry weight were found from the DME-1 treatment, followed by DME-2. As a result, DME combustion gas that raised the level of temperature and CO_2 concentration in the greenhouse-1 and greenhouse-2, might have an effect on growth of lettuce and Chinese cabbage. At end of experiment, the highest fresh and dry weight of lettuce and Chinese cabbage were measured in greenhouse-1 and followed by greenhouse-2. Similarly chlorophyll content of greenhouse-1 and greenhouse-2 were more compared to greenhouse-3. In general, DME was not producing any harmful gas during its combustion period, therefore it can be used as an alternative to conventional fuel such as diesel and liquefied petroleum gas (LPG) for both heating and CO_2 supply in winter season. Moreover, endorsed quantify of DME combustion gas for a specified crop can be applied to greenhouse to improve the plant growth and enhance yield.

Additional key words : carbon dioxide, chlorophyll, dry weight, fresh weight, temperature

Introduction

Lettuces and Chinese cabbages can be grown successfully either in spring or fall. However, there is a risk of environmental stress associated with exposing young plants to cold weather after field setting (Palada et al., 1987). It is well known that temperature and CO_2 are the two conclusory factors controlling the growth of plants (Berghage, 1998; Heins et al., 2000). Lettuce and Chinese cabbage species has an optimum temperature for rapid growth rate, however lower temperatures below the optimum range allow the plant to grow, but at a considerably reduced rate (Kalisz and Cebula, 2006). Nam et al. (1995) reported that the response of plants to unfavorable temperatures results in a modification of many physiological and biochemical processes leading to change in the chemical composition. The degree of these changes is mainly dependent on the temperature level, the temperature exposure duration and the stage of plant development. It is found that seedling stage of Chinese cabbage generally more sensitive to unfavorable thermal conditions than more developed plants (Daly and Tomkins, 1995). Low temperatures have been reported to reduce the growth of Chinese cabbage seedlings (Wiebe, 1990) and to influence their chemical composition (Moe and Guttormsen, 1985; Sasaki et al., 1996). Likewise temperature, elevated CO_2 may directly or indi-

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rectly have an effect on plant production and development. It has been observed that exposure of plants to elevated CO_2 resulted in a higher biomass production, an altered morphology, increased water use efficiency, increased photosynthetic activity and an enhanced carbohydrate content (Kimball, 1983; Cure, 1986; Smith et al., 1987; Lawlor and Mitchell, 1991; Woodward et al., 1991). However, the interspecific variation in response to elevated CO_2 would be related to the morphology and strategy of different plant species (Poorter, 1993; Loehle, 1995). Differences in growth rate, life span and sink strength between different species have been shown to influence the effect of CO_2 (Stulen et al., 1994).

Therefore, with growing concerns of controlling the factors (temperature and CO_2) in greenhouse for crop production, DME burner using DME gas may be one alternative technique in sustainable agricultural practice. DME which is clean and considered to be economically alternative fuel is produced from natural gas through synthesis gas (Semelsberger et al., 2005). It is proved that DME and LP gas has the almost similar properties (Ogawa et al., 2003). Nowadays, DME is used widely in various fields as a fuel such as power generation, transportation, home heating and cooking, etc. (Bhattacharya et al., 2013; Olah et al., 2009; Arcoumanis et al., 2008; Kim et al., 2008; Marchionna et al., 2008). In this study, DME gas was used as a fuel for DME burner to increase temperature and CO_2 concentration in greenhouse for lettuce and Chinese cabbage cultivation.

DME gas is a conversion form synthesis gas. The synthesis gas is transformed into DME through following two-step synthesis reactions (EBTP, 2011; Yuan and Eden, 2016). DME gas is also known as unpolluted fuel by burning it in agriculture facility, it is not only provide heating but also provide sufficient CO_2 without any high concentration of toxic gases.

$$2H_2 + CO \leftrightarrow CH_3OH\ (\Delta H0 = -90.56\ kJ\ mol^{-1})$$

$$2CH_3OH \leftrightarrow CH_3OCH_3 + H_2O\ (\Delta H0 = -49.43\ kJ\ mol^{-1})$$

$$CO + H_2O \leftrightarrow CO_2 + H_2\ (\Delta H0 = -41.12\ kJ\ mol^{-1})$$

To identify optimal amount of DME combustion gas supply to greenhouse, it is essential to quantify the complex crop–climate and phenology analysis. Many researches have been conducted to evaluate the process and application of DME for different sectors (Zhao et al., 2011; Zhang et al., 2016; Liu et al., 2013; Sun et al., 2014). However, a few number of experiments have been conducted to evaluate the impacts of DME on crop yield, especially in greenhouse where crops in winter season face low temperature stress (Basak et al., 2018; Qasim et al., 2018). Therefore, the objectives of this study were to (i) evaluate the changing pattern of temperature and CO_2 concentration applying DME in a control greenhouse system and (ii) determine the impacts of DME on chlorophyll content and fresh and dry weight of lettuce and Chinese cabbage.

Materials and Method

1. Experimental Design

This experiment was performed in three identical greenhouses (width 3 m, length 4 m, height 2.5 m) of Gyeongsang National University (Fig. 1). In all 3 greenhouses, there were 2 beds for planting vegetables. In one bed, lettuce was grown and, in another bed, Chinese cabbage was grown. Three tests were performed to compare and analyze the growth of lettuce and Chinese cabbage and chlorophyll content in greenhouses at different flow quantity of DME. DME supply times were 00.5 hr day^{-1}, 1 hr day^{-1}, 1:30 hrs day^{-1} and 2 hrs day^{-1} on week 1, 2, 3 and 4 respectively in every morning at 6 o'clock. The average DME flow quantity in duct was 17.4 m^3 min^{-1} and 10.2 m^3 min^{-1} to greenhouse-1 and greenhouse-2 and no DME gas was supplied to greenhouse-3 which was left as control (Fig. 2). For this experiment, lettuce and Chinese cab-

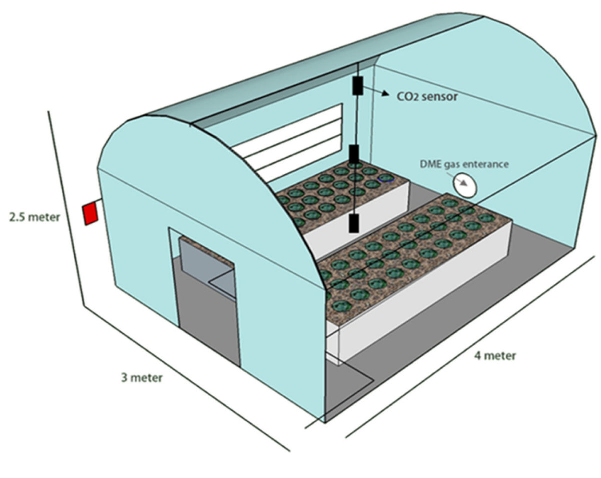

Fig. 1. Schematic diagram of Greenhouse for the experiment.

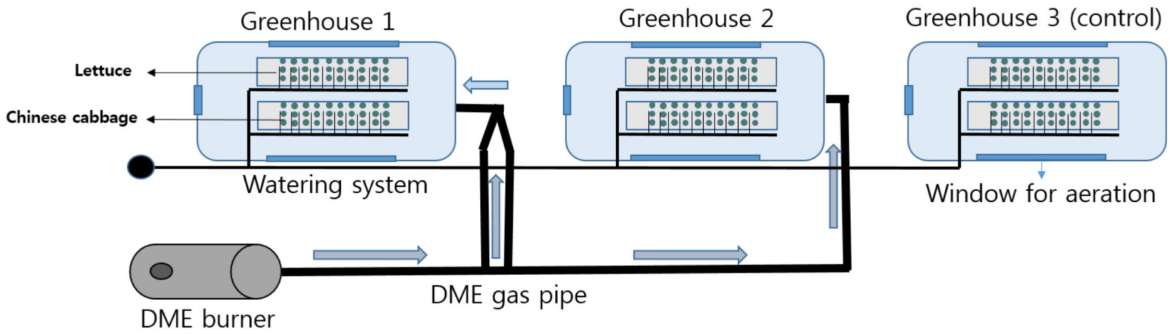

Fig. 2. Experimental design of DME supply to greenhouses.

Table 1. Physical properties of Dimethyl ether (DME)

Formula	CH_3OCH_3
Molecular weight (g mol^{-1})	46.07
Density (g cm^{-1})	0.661
Normal boiling point (℃)	-24.9
Carbon Content (wt%)	52.2
Hydrogen content (wt%)	13
Oxygen content (wt%)	34.8

*Density at P=1 atm and T= -25℃

Table 2. The specification of the DME gas burner

Items	Specification
Quantity of energy (kcal h^{-1})	40000
Rotational frequency of motor (rpm)	1495
Output of motor (W)	200
Quantity of flow (m^3 min^{-1}, CFM)	1060
Diameter of outlet (mm)	400
Length of burner (mm)	1360

Table 3. Concentration of gases during combustion of DME

Gases (unit)	Amount
CO_2 μmol mol^{-1} (ppm)	3316.1
H_2 μmol mol^{-1} (ppm)	0.7
CO μmol mol^{-1} (ppm)	11.6
CH_4 μmol mol^{-1} (ppm)	1.7
O_2 cmol mol^{-1} (%)	21.3
N_2 cmol mol^{-1} (%)	77.8

*samples were collected in front of DME burner

bage seeds were purchased from market and seeds trays were used for seedling. After 3 weeks, 30 lettuce and 30 Chinese cabbage plants were transplanted to two beds of greenhouses.

The irrigation systems were uniform in all three greenhouses. Water was provided by needles to each separate plant. The irrigation time was 2 min day^{-1} in all greenhouses. For aeration side windows were opened at 9:00 am and closed at 6:00 pm to keep the temperature in range.

2. Properties of DME

The physical properties of DME gas and the specification of DME burner are described in Table 1 and 2, respectively. For testing the concentration of gases, the samples were collected in air plastic bags (20 litter capacity) during operation of DME combustion. The sample was taken to Korean Testing laboratory on same day and ISO 6974-6 standard method was used for determination of gases concentration. The testing environment was (mean and S.D.) 19.8±5.20°C in temperature and 50.2±19.9% in relative humidity. Table 3 shows the concentration of gases during combustion of DME.

3. Data Collection and Analysis

The plants were periodically examined after the germination stage to observe the changing pattern of plant growth and DME treatment. For measuring carbon dioxide, temperature and humidity "Lutron MCH-383SD (Lutron Electronic Enterprise Co., Ltd., Taipei, Taiwan)" electrochemical sensors were set at three different height of greenhouses. Lutron MCH-383SD is equipped to record the date, time interval and has a memory card to store these data. Data were checked at 10-min intervals and recorded data were averaged for further analysis and interpretation. The lower sensor was equipped at height of 0.3m from floor which was equal with height of plants in bed.

Fresh weight and dry weight of leaves and roots of each plant in greenhouse-1, 2 and 3 were compared at end of the experiment. Fresh weight was measured as whole plant because of high number of leaves and size of lettuce. For Chinese cabbage, 5 big leaves from each plant were taken for measuring fresh and dry weight analysis. Roots were cleaned from soil and separated from whole plants for analysis. The fresh and dry weight of plant was estimated to use digital balance (model- FX-300iWP, A&D Company Limited, Tokyo, Japan) and drying oven (Shelves for 5E-DHG6310: 2 Layers, Changsha Kaiyuan Instruments Co., Ltd, China). Number of papers were followed various temperature range and time for measuring the dry weight of plant (e.g., Arshadullah and Zaidi, 2007; Cho et al., 2007; Karimi et al., 2009). In experiment, where different treatments of plants were studied, dry weight of plant was measured to keep temperature at 80°C for 24 hour. Standard statistical methods were used for data evaluation including analysis variance with a significance level of $P<0.05$. The significance differences between mean values of experimental data were tested with a post-hoc Tukey's HSD test. All statistical calculations were performed with Statistix10 and Statistical Package for the Social Sciences (SPSS Version: 22.0.0.0).

Results and Discussion

1. Temperature and CO_2 pattern

Environmental factors, like temperature and CO_2 are important at all stages of plant growth of lettuce and Chinese cabbage. It was examined the changing pattern of temperature and CO_2 concentration due to the different levels of DME applications. The result of the study showed that the higher levels of DME application accompanied with a greater diversity CO_2 concentration were confirmed the increased of temperature in this period (Fig. 3). Even the application of DME in an amount of 10.2 $m^3\ min^{-1}$ was efficient to increase temperature and CO_2 content in greenhouse-2. With 17.4 $m^3\ min^{-1}$ and 10.2 $m^3\ min^{-1}$ DME supply, the maximum CO_2 were recorded 1380 ppm and 940 ppm in greenhouse-1 and greenhouse-2 respectively. Average 24 hours data on temperature and CO_2 during experimental period showed that CO_2 concentration was increased up to 265% and 174% treated with DME at 17.4 $m^3\ min^{-1}$ and 10.2 $m^3\ min^{-1}$ respectively compared to control condition in every morning between time intervals at 6 to 8 o'clock. Due to increase the level of CO_2 in greenhouses in the same way of concentrations of DME, temperature increased up to 4.8°C and 3.1°C in greenhouse 1 and 2 respectively within this same time. On the basis of these results of changing different concentration CO_2 and temperature were chosen to examine those variability chlorophyll content and fresh weight and dry weight of plant for further work. Similar results were reported by other researchers which showed that CO_2 and temperature are constantly associated with the application of DME gas in greenhouse (Basak et al., 2018; Qasim et al., 2018).

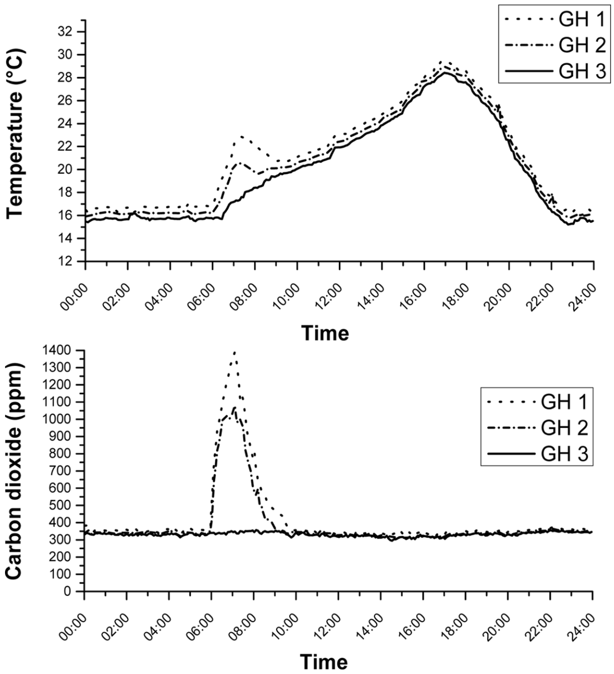

Fig. 3. Changing pattern of temperature and CO_2 concentration inside the three greenhouses. The data of the figures show the mean values of the two parameters during the DME application rate was 1 hr day^{-1}.

2. Fresh and Dry weight of Lettuce and Chinese cabbage

Twenty five plants of lettuce and Chinese cabbage were collected from each greenhouse and measured the fresh and dry weight. The evaluation of the fresh and dry weight of lettuce and Chinese cabbage under different application rate of DME (DME-1, DME-2 and DME-3) in the experimental period is presented in Fig. 4 and Fig. 5. Fresh weights of lettuce were significantly different among the three treatments and time. It was maximum for DME-1 treatment compared to other two treatments. Mean (±SD)

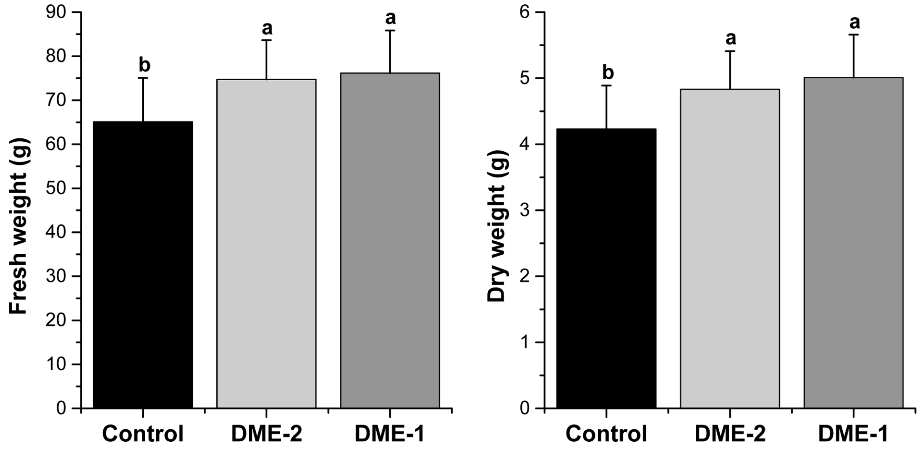

Fig. 4. Data represent means and standard deviation (SD) of fresh and dry weight of lettuce in 8th week in three treatments in greenhouses (n=25). Different letters above the bars (SD) denote significant differences of fresh and dry weight among treatments at $p \leq 0.05$ based on Tukey's HSD post-hoc test.

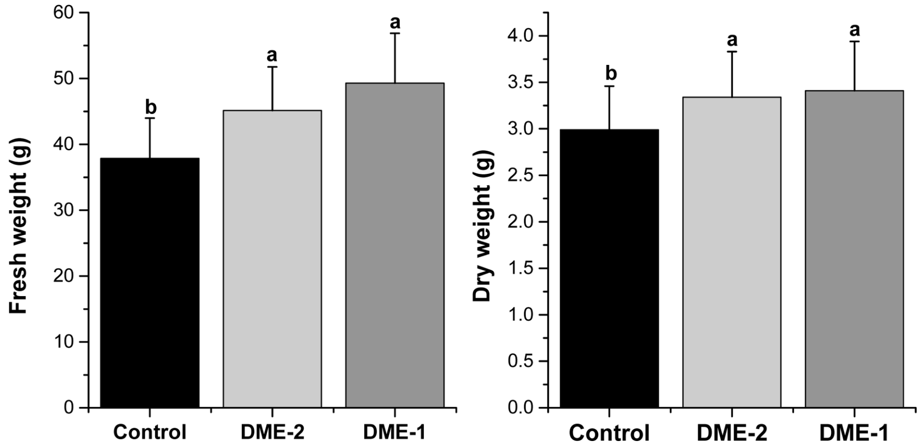

Fig. 5. Data represent means and standard deviation (SD) of fresh and dry weight of Chinese cabbage in 8th week in three treatments in greenhouses (n=25). Different letters above the bars (SD) denote significant differences of fresh and dry weight among treatments at $p \leq 0.05$ based on Tukey's HSD post-hoc test.

fresh weight in gram after 8 weeks were 76.1±9.7, 74.7±8.9 and 65.1±9.9 for DME-1, DME-2 and DME-3 respectively. The study found that the differences of fresh weight were significant ($p<0.05$) among DME-1, DME-2 and DME-3. In this current experiment, it was also examined that fresh weight increased up to 17.1% due to application DME at a rate of 17.4 m^3 min^{-1} and 14.8% for 10.2 m^3 min^{-1} compared to control treatment, thus revealing the increase in fresh weight of lettuce due to increase the amount of DME application. Moreover, due to growing time, dry weight increased at a substantial rate. It was also observed that the dry weight plant whose are directly related to fresh weight, did not keep the same rate within this experimental period. Dry weight values following declined gradually 5.01±0.65, 4.8±0.58 and 4.2±0.65 for DME-1, DME-2 and DME-3 respectively after 8 weeks. Thus, higher dry weight was obtained for the treatments, DME-1 and DME-2 whereas the minimum dry weight of plant was observed for DME-3.

Likewise, lettuce both different rates of DME application also affect the fresh and dry weight of Chinese cabbage. Five big leaves from each plant of Chinese cabbage were taken for measuring fresh weight and dry weight analysis. When DME was applied at a rate of 17.4 m^3 min^{-1} in greenhouse, fresh and dry weight of Chinese cabbage markedly increased at a range of 30.1% and 14.1% respec-

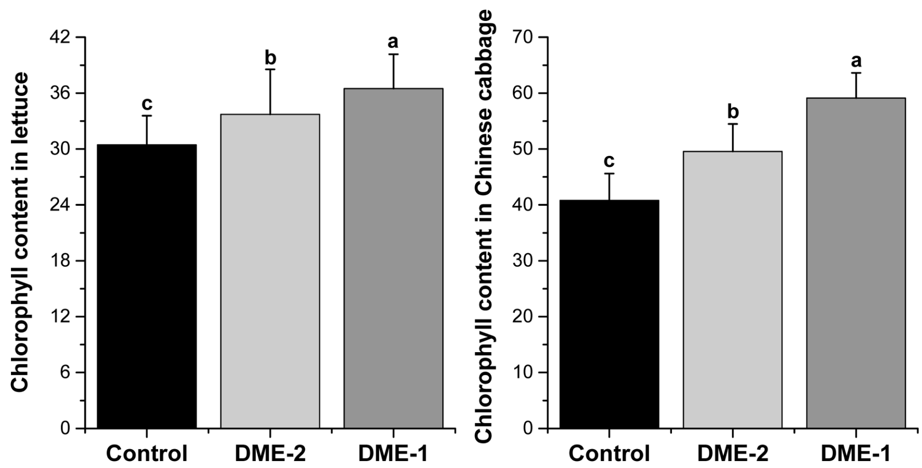

Fig. 6. Data represent means and standard deviation (SD) of chlorophyll content of lettuce and Chinese cabbage in 8th week in three treatments in greenhouses (n=25). Different letters above the bars (SD) denote significant differences of chlorophyll content among treatments at $p \leq 0.05$ based on Tukey's HSD post-hoc test.

tively relative to the control treatment. In response to DME at a rate of 10.2 m^3 min^{-1}, fresh and dry weight increased up to 19.3% and 11.7% respectively. DME-1 and DME-2 treatments which caused rise in temperature and CO_2 in greenhouse was found to have an effect on the fresh and dry matter of lettuce and Chinese cabbage seedlings. Temperature of 18 to 22°C was optimum for Chinese cabbage heading and 10 to 13°C for the final head development, with growth reduction occurring when temperature is below 10°C (Burt et al., 2006). According to Moe and Guttormsen (1985), the increase of temperature in the growing stage resulted in higher dry matter of Chinese cabbage seedlings. A marked increase of fresh matter in Chinese cabbage grown at higher temperatures also observed by Noto and Leonardi (1995). On the other hand, the reduction in growth of cabbage seedlings held in low temperature was observed by Sasaki et al. (1996). Wiebe (1990) mentioned that the number of leaves in Chinese cabbage seedlings raised clearly with higher temperature compared with those subjected to low temperature. Likewise, temperature elevated CO_2 may directly, or indirectly, effect on plant production and development. It has been noted that exposure of plants to elevated CO_2 resulted in a higher biomass production and an enhanced carbohydrate content (Lawlor and Mitchell, 1991; Woodward et al., 1991). Similar effect was described by Gray (2015) for lettuce plant. The results obtained in this study indicated that DME application during growing stage were more beneficial for plant growth.

3. Chlorophyll content in Lettuce and Chinese cabbage

The chlorophyll content results are presented as an average of the measurement in all 3 greenhouses (Fig. 6). DME application levels had a significant ($p<0.05$) effect chlorophyll content in lettuce and Chinese cabbage. The mean values of chlorophyll content in lettuce were recorded 36.48±3.7, 33.7±4.8 and 30.4±3.1 for DME-1, DME-2 and DME-3 respectively at the end of 8th week. However, the mean values of chlorophyll content in Chinese cabbage were obtained 59.1±4.5, 49.5±4.9 in DME-1 and DME-2 respectively where it was 40.8±4.8 for DME-3. Thus, chlorophyll content was obtained high for the treatments DME-1 and DME-2 whereas the minimum chlorophyll content was observed for DME-3. So from these results it is suggested that DME supply to greenhouse occurred high CO_2 can be effective for chlorophyll content of leaves. CO_2 being the substrate of photosynthesis, the increase in CO_2 concentration increases the net photosynthetic rate and crop productivity (Kimball, 1983; Ziska et al. 1997). In reviewing a number of studies of the effects of CO_2 on enrichment of leaf chlorophyll content (Evans, 1989; Gifford, 1992; Houpis et al., 1988; Idso and Kimball, 1992; Idso et al., 1991; Idos et al., 1993). Pinter et al. (1994) observed slightly higher per-unit-leaf-area chlorophyll contents in plants exposed to elevated CO_2. In another experiment with alfalfa, for example, plants grown at an atmospheric CO_2 concentration of 600 ppm actually displayed greater leaf chlorophyll concentrations than those observed in plants grown at 340 ppm (Sgherri et al., 1998).

Conclusions

The current study demonstrates the effects of DME combustion gas on fresh weight, dry weight and chlorophyll content in lettuce and Chinese cabbage, which are important factors for higher yields. Higher concentration of CO_2 generated by DME combustion gas in greenhouse showed higher efficiency on fresh weight, dry weight and chlorophyll content of plant. The result of the study showed that, fresh and dry weights of lettuce and Chinese cabbage in greenhouse-1 obtained from DME-1 (17.4 m^3 min^{-1}) treatment were higher compared to other two treatments (DME-2 and DME-3). Moreover, the contents of chlorophyll were better in greenhouse-1 and 2 as compared to control greenhouse. To improve the yield, in response to the above mentioned three parameters, DME gas usage is important in developing new decision making by farmers and researchers for its application under extreme cold condition in greenhouse. Moreover, this study creates a scope for further research using DME combustion gas in greenhouses to measure growth performance of different crops. In addition, it is essential to quantify the accurate rate of DME combustion gas for a specified crop, which can be helpful to improve the plant growth and enhance yield.

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온실에서 상추와 배추를 이용한 DME 원료 난방 효율분석

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적 요. 본 연구는 온실의 온도와 CO_2농도를 높이기 위해 DME버너용 연료로 DME가스를 사용했을 때 DME 연소가스의 성능을 결정하고 겨울에 상추와 양배추의 엽록소 함량 그리고 무게와 건조무게에 대한 영향정도를 조사하기 위해 수행되었다. 각각 온실1과 온실2에 처방 된 DME-1과 DME-2 처방은 덕트의 평균 DME 유량 17.4 m^3 min^{-1}과10.2 m^3 min^{-1}으로 구성됐으며, 대조군(DME-3)으로 남겨진 온실3에는 DME 가스가 공급되지 않았다. DME 공급 시간은 각각 주차 별로 1주차는 하루당 0.5시간, 2주차는 1시간, 3주차는 1.5시간, 4주차는 2 시간으로 설정하였다. 각각 처방마다 엽록소 함량과 상추와 배추의 건조 전, 후 중량을 측정했으며, 연구결과 무처리구인 온실3과 비교하여 온실1과 온실2 의 CO_2 농도는 각각 265%, 174% 증가하였고, 온도의 경우 4.8°C, 3.10°C 상승하였다. DME 가스를 제외한 다른 조건이 같은 온실에서 재배된 상추와 양배추의 엽록소 함량과 생체중, 건물중은 온실1에서 (유의적으로) 가장 높았으며, 온실2는 대조구 온실보다 높았다. 이러한 결과는 DME가스 연소에 의한 CO_2 농도 차이에 기인된 것으로 판단된다. 일반적으로 가스연소에 의해 발생되는 유해가스 증상은 나타나지 않았으며 동절기 난방과 CO_2 공급이 동시에 필요할 경우 DME가스가 기존의 경유 또는 LPG 등을 대체할 수 있는 가능성을 확인하였다. 향후 정밀한 연구를 통하여 효율적인 난방방식으로의 검토가 적극 필요하다고 판단된다.

추가 주제어: 이산화탄소, 엽록소, 건물중, 생체중, 온도