Indoor production of loose-leaf lettuce (*Lactuca sativa* L.) using artificial lights and cooling system in tropical lowland

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Abstract. In the Philippines, crop production hindrances are climate change effects, typhoon occurrences, seasonal dependent cropping pattern and decreasing farm areas. There is a need to strategize farming technologies. Controlled environment agriculture (CEA) has potential in addressing these issues. A farming set-up in controlled environment was developed using locally available materials, light emitting diodes (LED) as sole-source of light and cooling system for temperature manipulation. This study was conducted to benchmark temperature and light intensity requirements for growing loose-leaf lettuce in lowland tropics. Light intensities of 50, 100 and 150 $\mu\text{mol m}^{-2} \text{s}^{-1}$ were tested under temperature settings of 25 °C and 18 °C. Carbon dioxide and relative humidity were maintained at recommended levels. In actual chamber condition, average day/night temperatures inside were 25.3 $\pm$ 0.4/25.5 $\pm$ 0.2 °C and 18.9 $\pm$ 0.6/18.7 $\pm$ 0.3 °C, for the first and second cycles, respectively, whereas, day/night temperatures outside chambers were 29.6 $\pm$ 2/25.9 $\pm$ 0.5 and 26.2 $\pm$ 1/23.6 $\pm$ 0.6 during the first and second cycles, respectively. Under two temperature settings, best yield per unit area was observed at required light intensity of 150 $\mu\text{mol m}^{-2} \text{s}^{-1}$. No significant difference in productivity was observed under 25 °C and 18 °C. Also, no significant difference in productivity was observed between plants in two temperature settings and plants outside.

1 Introduction

Controlled environment agriculture (CEA), the cultivation of plants in enclosed environment in which growth factors are carefully controlled and programmed [1] has become a trend, especially in developed countries. CEA has been done both in completely indoor setting and greenhouse [2]. Commercial crop production and researches are conducted under environmentally controlled spaces [3] in which abiotic factors such as light, water carbon dioxide, temperature and management options like planting material and fertilizer application are manipulated [4].

In the Philippines, greenhouse has been adapted both in upland [5] and lowland [6]. However, initiatives are still done to encourage production in greenhouse than in open field [7]. The frequent occurrence of typhoon decreases production [8] and might as well threatens to destroy greenhouse structures. Moreover, production in the country is seasonal dependent. In a tropical lowland setting, greenhouse problems still arise due to temperature rise inside the structure [6, 9], thus the need to control environment favourable for crops. Indoor farming offers a lot of potentials in terms of food sustainability [10] and increased productivity, as crops can be planted all-year round. With this system, plants can be more resilient to typhoons and climate change

effects such as flood or drought. This study was conducted to benchmark temperature and light intensity for loose-leaf lettuce as test crop.

2 Methodology

Three chambers were constructed using locally available materials with each having floor area of 2.5m x 6.0m and ceiling height of 2.5m. Each chamber was equipped with two 1hp window-type air-conditioning units (AC) operated alternately for 12 hours, two 70-watt circulating fans, and two sprinkler foggers (Figure 1). Plants were provided with 150, 100 and 50 $\mu\text{mol m}^{-2} \text{s}^{-1}$ photosynthetic photon flux (PPF), for 14 hours. ECOLUM LED T8 tube lights, 6500K daylight were used such that 4, 3 and 2 tubes would provide PPF of 150 (L_3), 100 (L_2) and 50 (L_1), respectively. Also, planting bench with dimension of 1m x 5m x 0.8m was installed in each chamber. Planting pots (20cm x 20cm x 14cm) containing 1800g substrate mixture with 1:1:1 ratio by volume of garden compost, carbonized rice hull and vermicast, added with 2000 mL water was planted with two 15 days old fanfare (grand rapid or green ice) lettuce. Plants were grown in three rows along length of planting bench and harvested at 24 days after transplanting (Figure 2). Lettuce plants were also grown outside the chamber for comparison.

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Figure 1. Components of the constructed CEA system

Figure 2. Plants grown in rows under LED T8 daylight

Temperatures of 25 °C (T_1 , first cycle) and 18 °C (T_2 , second cycle) were tested using the air-condition system. Carbon dioxide (CO_2), temperature and relative humidity (RH) were monitored using Desktop CO_2 Monitor 7788 Green Day Model by AZ Instruments Corp., Taiwan. PPF levels in each chamber were also monitored using Handheld Quantum Meter with integral sensor MQ-100 Model by Apogee Instruments Inc., USA.

2.1 Pre-test operation

Temperature and light distributions were evaluated prior to crop establishment. Without the plants inside the chambers, cooling system was operated to check the temperature distribution. Temperature was measured in 40 locations within the planting bench. On the other hand, light distribution was assessed by measuring the

light intensity below the lighting fixture with the sensor at soil level approximately 13 cm from the LED tubes.

Three frequencies of monitoring environmental parameters such as temperature, CO_2 and RH were put to trial; hourly, every two hours and five measurements in a day or within 24 hours.

2.2 Monitoring of environmental parameters

2.2.1 Light intensity

Monitoring light intensities were done daily, one hour before lights on and one hour after lights off. Measurement was done by positioning the sensor at canopy level just below the lighting fixture [11-12]. As observed, the PPF value changed over time especially when the crop grows. Thus, to maintain PPF values of 50, 100 and 150, the height of the lighting fixtures were adjusted; a technique employed in other studies [13-15].

2.2.2 Temperature, CO_2 and RH

During crop establishment, temperature, CO_2 and RH were monitored daily at daytime (lights on) and night-time (lights off).

Hourly monitoring was necessary to monitor RH and to operate foggers, if its value reached 50%. During pre-test operation (hourly), no significant differences in temperature, CO_2 and RH were observed from 9:00 pm to 5:00 am. This was the night time condition. To acquire representative data for night condition, measurements were taken at 5:00am and at 9:00pm. Daytime measurements were taken hourly from 6:00 am to 8:00 pm. This monitoring schedule was based on the results of the pre-test operations.

3 Results and Discussion

3.1 Temperature and light Distribution

Temperature was found evenly distributed within the chamber. Also, light intensities of lighting fixture in each chamber were found with no significant differences between plant rows.

3.2 Environmental parameters in the chamber

3.2.1 Light intensity

Light intensities were within the range required for the treatments (Figures 3 and 4). There were fluctuations in average daily PPF because light intensity at canopy level was influenced by lettuce's growth. As leaves reached closer to the light source, PPF readings became higher. Adjustment of the height of lighting fixtures (about 5cm higher) then caused lower light intensity readings. PPF trend of L_3 varies from L_2 and L_1 . For the first cycle, this occurred at 11-14 days, while for the second cycle at

Figure 3. Average daily PPF measured at first cycle (25 °C)

Figure 4. Average daily PPF measured at second cycle (18 °C)

21-23 days. The disparity was influenced by the difference in plant height response (data not shown) under 25 °C and 18 °C. Thus, the adjustment time of lighting fixtures also varies. Also, light intensity in chamber changes over time in a day even with the light sensor placed at same location [16].

3.2.2 Temperature, CO₂ and RH

Figures 5 and 6 show the actual day and night temperatures inside the chambers with the AC thermostat settings of 25 °C and 18 °C. In both settings, the current system achieved the required temperature treatments. Also, CO₂ and RH were maintained at levels required for normal plant growth.

Temperature is important since it controls the rate of plant growth [17], its physiological and chemical processes [17-18]. During first cycle, average day and night temperatures within chambers were 25.3±0.4 °C and 25.5±0.2 °C, respectively. Chamber temperatures during second cycle planting were 18.9±0.6 °C during day and 18.7±0.3 °C during night. Day and night temperatures outside the chambers were 29.6±2/25.9±0.5 and 26.2±1/23.6±0.6 during the first and second cycles, respectively.

Carbon dioxide (CO₂) levels were within acceptable range of 380 ppm [19] to 1500 ppm [20] and recommended levels of 800-1200 ppm [3]. Average day and night CO₂ inside the chambers were 496.1± 22 and

Figure 5. Day temperature at 25 °C and 18 °C setting

Figure 6. Night temperature at 25 °C and 18 °C setting

520.2± 37 ppm, respectively, during first cycle, and 463.7 ±35 ppm and 464.2±34 ppm, respectively during second cycle. Other researches had maintained CO₂ levels close to what were observed [21-23]. Thus, required CO₂ for plant's normal growth was achieved.

Relative humidity (RH) in the chambers was maintained according to acceptable RH of 40 - 80% [3] avoiding water stress, since RH affects plant water take up [3] and transpiration rate [17]. Average day and night RH within chambers were 65.8 ± 4 and $80.3 \pm 3\%$, respectively, during first cycle, and 62.5 ± 5 and $75.6 \pm 5\%$, respectively, during second cycle. Thus, relative humidity within chambers was sufficient enough for plant to perform normal physiological processes.

3.3 Yield performance of loose-leaf lettuce

On the average, yield of fanfare lettuce reached 29.6 grams per plant covering a planting density of about 14 plants per square meter. With the system, area productivity (grams of lettuce per square meter planted) was best under highest light intensity of $150 \mu\text{mol m}^{-2} \text{s}^{-1}$ at both temperature settings (Table 1). Analysis of variance in CRD showed that at 25°C , L_3 with area productivity of 400.79 grams of lettuce harvested per square meter was significantly higher than those under treatments L_2 and L_1 . Similarly, at 18°C , L_3 with area productivity of 423.02 g m^{-2} , was significantly higher than those under L_2 and L_1 . These results were comparable to other study where fresh weight of lettuce significantly increased at higher light intensity [24]. Using T-test (data not shown), no significant difference was found on the area productivity of lettuce at 18°C and 25°C temperature setting. Also, productivity of lettuce inside the chambers, at both temperature setting, were not significantly different from those outside the chambers with area productivity of 316.67 g m^{-2} .

Table 1. Area productivity (g m^{-2}) of loose-leaf lettuce

Light Intensity ($\mu\text{mol m}^{-2} \text{s}^{-1}$)	First Cycle, T_1 (25°C)	Second Cycle, T_2 (18°C)
50 (L_1)	102.38 ± 26^c	126.99 ± 44^c
100 (L_2)	284.92 ± 71^b	257.14 ± 56^b
150 (L_3)	400.79 ± 95^a	423.02 ± 113^a

Means of the same column with same letter are not significantly different by LSD at 95% level of confidence

4 Conclusions and Recommendation

The constructed CEA system can maintain average temperature within the selected temperature settings of 18°C and 25°C . In conclusion, the system can produce loose-leaf lettuce at both temperature settings. However, it is highly recommended that the light intensity should be set at least $150 \mu\text{mol m}^{-2} \text{s}^{-1}$ for better crop performance. Also, improvement can be made on the lighting system. Although not included in the study, lettuce was found to be bitter at 25°C . Thus, temperature settings between 18°C and 25°C can be tested. As such, the maximum temperature setting that

will give the lowest power consumption which will not produce bitter lettuce can be determined. Further studies on quality of lettuce, other lettuce varieties and other cultivars as test crops, are recommended.

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