# The effect on the growth and yield of green leaf Romaine lettuce (*Lactuca sativa* L.) in a vertical aeroponic system

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**Abstract**: The growth and yield of green-leaf Romaine lettuce grown under a tropical greenhouse using a vertical aeroponic system with rootzone cooling were evaluated in this study. The experiment was set up using a Combined Analysis in Strip-Plot design in a 6m x 12m greenhouse wherein the two root zone cooling methods, a ground heat exchanger (GHE) and improvised chiller, were the treatments while harvest periods of 20, 25, and 30 days after transplanting (DAT) were the horizontal factors, and the levels of the tower (top, middle and bottom) were the vertical factors. The IRRI-Statistical Tool for Agricultural Research (STAR) was used for data analysis. Results revealed that longer and broader leaves and higher yields were observed using the improvised chiller and were harvested from the top of the tower at 30 DAT. In terms of growth, the best combination of factors was from those harvested from the top of the tower that used an improvised chiller and harvested at 30 DAT. The yield at 30 DAT using an improvised chiller was significantly higher at 78.61 grams compared to using GHE with only 60.47 grams. The Economics of using GHE and improvised chiller in green-leaf Romaine lettuce production harvested at 30 DAT in a small area of 18 $m^2$ was found comparably feasible and viable. The former, however, showed better economic indicators with a potential annual net income of $1160.56, ROI of 42%, and a payback period of 2.41 years.

**Keywords**: tropical greenhouse, rootzone cooling, vertical aeroponics

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## 1 Introduction

The rapid population growth entails a high demand for food to feed the growing population. However, extensive land conversion from agricultural to industrial and residential classifications compromised the country's food supply. According to IBON Foundation (2017), the Philippines has about 98 939 hectares of land approved for conversion by the Department of Agrarian Reform from 1988-2016, while 165 000 hectares of irrigated prime agricultural lands are converted to other uses annually. The more land conversion to non-agricultural use, the lesser agricultural production would lead to limited supply and a rise in the cost of commodities.

Moreover, the climate change being experienced nowadays and the shortage of water in some areas also affect crop and food production, thus, a sustainable food production technology is needed which will produce a large amount of food in a limited space, requiring less amount of water, and which will not be affected by changing environmental conditions. Conventional production of temperate vegetables like

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lettuce is mostly cultivated in higher elevation farms to have better growth and acceptable taste. It can also be grown in lowland or high-temperature farms, but it will have a bitter flavor (Al-Said et al., 2018). Temperate vegetable production in the lowland could increase production, decrease delivery cost, and eliminates postharvest damage and losses hence lowering its market price. The controlled environment agriculture (CEA) or protected agriculture technology is a promising innovation in agricultural production. It enhances the environment of the plant to achieve optimum growth, extend the growing season, and increase crop yields by utilizing less space and water. In CEA, both the rootzone and aerial environment were being controlled and usually done in a greenhouse or an enclosed structure.

The environmental requirement in cultivating lettuce and the susceptibility of the country to typhoons and extreme heat limit production in lowland and arable areas. The variability of soil type, fertility, and limited production area also restrict large commercial-scale of lettuce production. Moreover, production in a greenhouse without considering the environmental requirement of the plant does not produce the same quality as that produced in cold and elevated farms. The need to create a system where appropriate temperature and the right amount of nutrients for proper growth and quality in lettuce production is essential.

This study was conceptualized to address the above-mentioned issues on environmental condition requirement of producing lettuce in a tropical location by planting in vertical aeroponics, using rootzone cooling technology, providing lower temperature inside the greenhouse and consuming less amount of water and producing higher yield and quality green-leaf Romaine lettuce.

The main objective of this study is to determine the growth and yield of green-leaf Romaine lettuce produced in a vertical aeroponic system with rootzone cooling, Specifically, the study seeks to set up a vertical aeroponic system with rootzone cooling; determine and compare the growth and yield of lettuce in the different height of the vertical aeroponic system with rootzone cooling at different harvest periods; and perform an economic analysis. The effect of root zone cooling using a ground heat exchanger (GHE) and the improvised chiller on the yield and growth of lettuce was observed, as also the effect of using vertical aeroponics on the different heights of the tower.

## 2 Materials and methods

### 2.1 The controlled environment

The controlled environment agriculture or protected agriculture technology referred to as tropical greenhouse or greenhouse in this study was used to grow green leaf Romaine lettuce (*Lactuca sativa* L.). The greenhouse measures 12 m long, 6 m wide, and a height of 5 m with combined plastic and screen enclosure and a top covering using ultraviolet-resistant transparent plastic. The sidings were wrapped with a fine mesh insect net that allowed natural ventilation and air circulation and prevented insect entry. Another UV-resistant plastic layer was installed below the top cover to diffuse the concentration of sunlight and served as protection for plants from the mist that comes out from foggers when activated.

The greenhouse was installed with: (1) Automated air-cooling system, to cool the ambient temperature inside. Automated foggers below the top cover and exhaust fans located in front of the greenhouse were used to reduce heat accumulation inside. The highest recorded temperature inside and outside the greenhouse was 31.2ºC and 32ºC, respectively, at 1 PM. However, the average temperature inside the greenhouse was 27ºC which is almost 1º lower than the average outside temperature of 27.87ºC. This average inside temperature is within the recommended temperature between 25ºC to 30ºC (Lakhiar, 2018). Moreover, the average relative humidity was 59%, which is within the recommended relative humidity of 50-70% (Brechner and Both, 2012); (2) aeroponic towers, wherein green-leaf Romaine lettuce was transplanted, and pipings for the flow of nutrient solution were installed; and (3) root zone cooling systems: GHE and chiller were used to cool the nutrient solution before reaching the root zone

*Ground Heat Exchanger (GHE)* - The GHE is a passive cooling system using buried pipes that transfer heat from the air to the underground (Figure 1). One end of the pipe serves as inlet for warm air and the other end as an outlet, which releases air of lower temperature. Cooling takes place through the conduction of heat transfer between the air and soil (Pascual, 2018). A 1.5HP was used to suction the nutrient solution (NS) from the tank placed below the ground to flow inside the nutrient solution pipe (blue pipe), while the blower was used to force air into the air pipe (orange pipe). After passing through the GHE, nutrient solution and air goes back inside the greenhouse. The NS flowed through the insulated PE pipe to the towers, while forced air was blown below the towers. The nutrient solution was delivered to the roots using low-pressure nozzles.

Figure 1 The ground heat exchanger (T1)

Three towers were randomly selected and placed with three sensors positioned at the top (X), middle (Y), and bottom (Z) parts of each tower. The GHE lowers the temperature of the nutrient solution from 26.9$^{o}$C to an average temperature from the three levels of the tower of 24.44$^{o}$C or a temperature difference of 2.47C$^{o}$, with the lowest temperature at the bottom (Z) of 23.7$^{o}$C.

*Improvised Chiller* - a 2 Hp improvised chiller was used to cool the nutrient solution for Treatment 2 (Figure 2). The evaporator of an air-conditioning unit was immersed in the chiller tank to cool the nutrient solution while the other parts of the aircon were installed outside the greenhouse. Cooled nutrient solution flowed through the insulated PVC pipes (blue arrow in Figure 2) and pumped to the aeroponic towers and further delivered to the root zone through the low-pressure nozzle. The drained nutrient solution was pumped back into the improvised chiller (red arrow in Figure 2).

Using the improvised chiller, nutrient solution temperature decreases from 26$^{o}$C to an average of 16.8$^{o}$C before it was delivered to the root zones. However, the temperature increases to an average of 20.06$^{o}$C at the root zone, with the lowest temperature of

19.82°C at the top of the tower and the highest temperature of 21.22°C at the bottom of the tower.

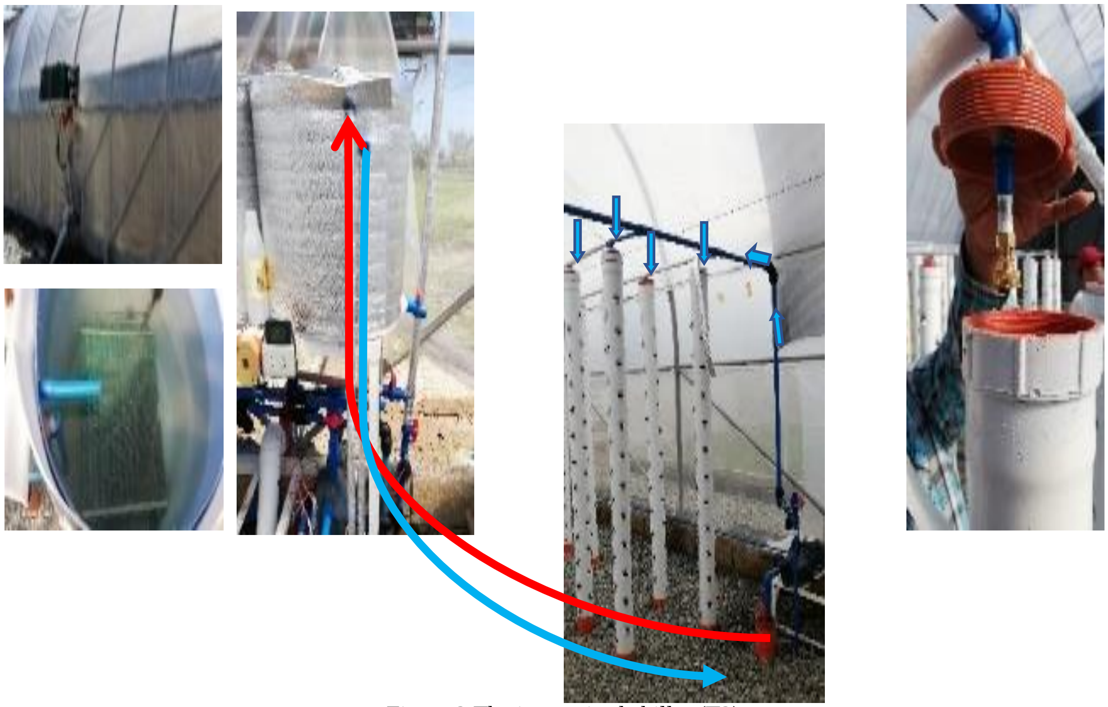


Figure 2 The improvised chiller (T2)

## 2.2 Lettuce production and management

The green-leaf Romaine lettuce (*Lactuca sativa* L.) was the test crop of the study and was grown inside the greenhouse according to the design of the experiment. Lettuce seeds were germinated in seedling trays using pumice and allowed to grow for 15 days in a shaded area. After germination, plants were transferred in a slit of a 5.08 cm length × 2.54 cm width sponge or foam soaked in water and allowed to grow further in a shaded area for another 15 days to stabilize the roots. After root stabilization, plants in sponges were placed into the holes of aeroponic towers and continuously wetted over by cooled nutrient solution up to the time of harvest (Figure 3).

## 2.3 Nutrient solution management

The study used a simple nutrient addition program (SNAP) solution, a locally formulated hydroponics nutrient solution developed by the University of the Philippines in Los Baños in collaboration with the Department of Agriculture-Bureau of Agricultural Research (DA-BAR). The SNAP solution was used throughout the plants' production period. It was mixed manually with water at a ratio of 200 L water: 500 mL SNAP A: 500 mL SNAP B.

## 2.4 Experimental setup and data analysis

The experiment was laid out following a combined analysis by strip-plot design with three blocking per treatment:

Treatments:

$T_1$ **-** with rootzone cooling using GHE

$T_2$ **-** with rootzone cooling using water chiller

Vertical Factor = Level of tower

Top (X), Middle (Y) and Bottom (Z)

Horizontal Factor = Harvest periods

$B_1$=20 days after transplanting (DAT),

$B_2$=25 DAT & $B_3$=30 DAT

All treatments were done simultaneously inside the greenhouse. Each block has 4 aeroponic towers with 48 plants per tower or a total of 36 aeroponic towers for each treatment. Data gathered were analyzed using the Analysis of Variance (ANOVA) for combined analysis in strip-plot design. Comparison among means will be done using Tukey's Honest Significant Difference (HDS). Statistical analysis was done using the

Statistical Tool for Agricultural Research (STAR) developed by IRRI (2013).

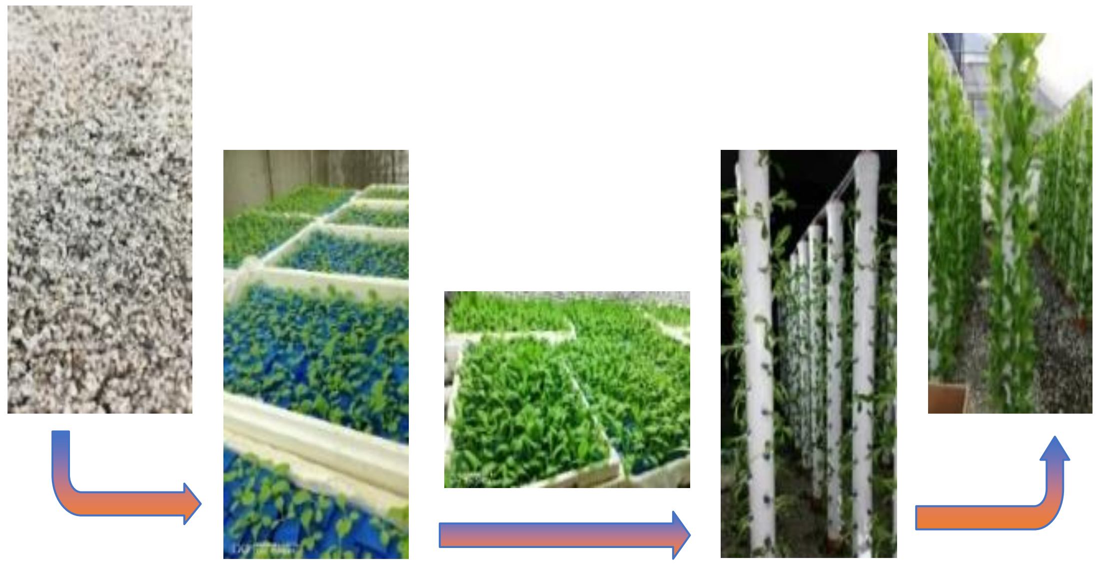


Figure 3 Lettuce production in vertical aeroponics

## 3 Results and discussion

### 3.1 Plant growth and yield

Leaf length, leaf width, and yield were measured and analyzed to determine the effect of using the rootzone cooling method (GHE and chiller) applied, harvesting periods, as well as the level of the tower wherein lettuce was planted and harvested.

### 3.2 Leaf length

Figures 4 and 5 show the leaf length of Romaine lettuce as affected by different root zone cooling methods, harvesting periods, and levels of the tower. Lettuce whose nutrient solution was cooled by the chiller and harvested 30 DAT and from the top of the tower had the longest leaves with a mean of 23.79 cm and 22.77 cm, respectively. While those lettuce whose nutrient solution was cooled by the GHE and harvested from the bottom part of the tower at 30 DAT had the shortest leaf length of 20.82 cm and 21.58 cm, respectively.

Analysis of variance showed significant differences between rootzone cooling methods and levels of tower and no significant differences were found among harvest periods and the interactions of rootzone cooling methods, harvest periods, and levels of towers. Comparison among means of rootzone cooling methods at each harvest period and level of tower further showed that lettuce whose roots were cooled by chiller in any harvest period had significantly longer leaves than that lettuce whose roots were cooled using GHE. Also, the leaves of those harvested from the top of the tower in either rootzone cooling methods or in any harvest period were significantly longer than those harvested from the bottom layer but had no significant difference from the middle layer of the tower (Figure 6). It seems that using a chiller as a rootzone cooling method favored the growth of green-leaf Romaine lettuce as far as leaf length is concerned. The plants that were transplanted on the upper and mid portion of the tower were better than those plants in either of the rootzone cooling methods.

### 3.3 Leaf width

The width of leaves as affected by different rootzone cooling methods, varying harvest periods, and levels of towers are shown in Figures 7 and 8. The leaf width of those harvested from the top of the tower using the chiller have the broadest leaf at 9.27cm, while those harvested from the bottom of the tower using GHE as the root zone cooling method have the narrowest leaves with a mean of 7.20 cm. Moreover, lettuce that uses a chiller as the root zone cooling method and harvested at 30 DAT had the broadest leaf of 9.20 cm.

Analysis of variance showed significant differences among the levels of towers, but no significant differences between the rootzone cooling methods, harvest periods, and the interactions between rootzone cooling methods and harvest periods and levels of towers. Comparison among means revealed that all plant samples have relatively the same leaf width regardless of the rootzone cooling method used and harvest period. However, those harvested from the top layer of the tower in either rootzone cooling methods and any harvest period have significantly broader leaves than those harvested from the bottom but have no significant difference with those harvested from the middle part of the tower while those harvested from the middle have no significant difference with those harvested from the bottom.

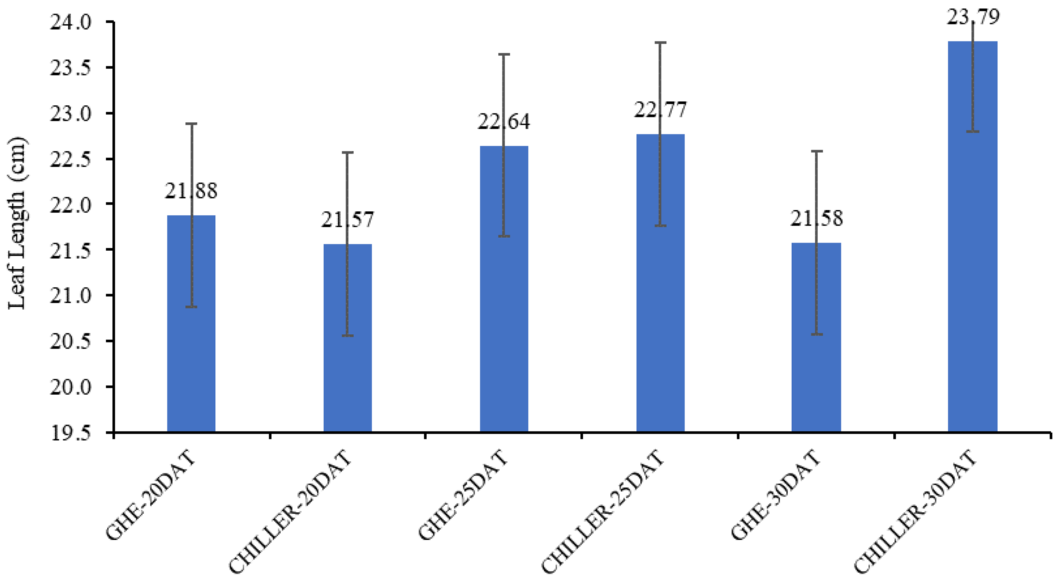



Figure 4 Length of lettuce as affected by different rootzone cooling methods and harvest periods

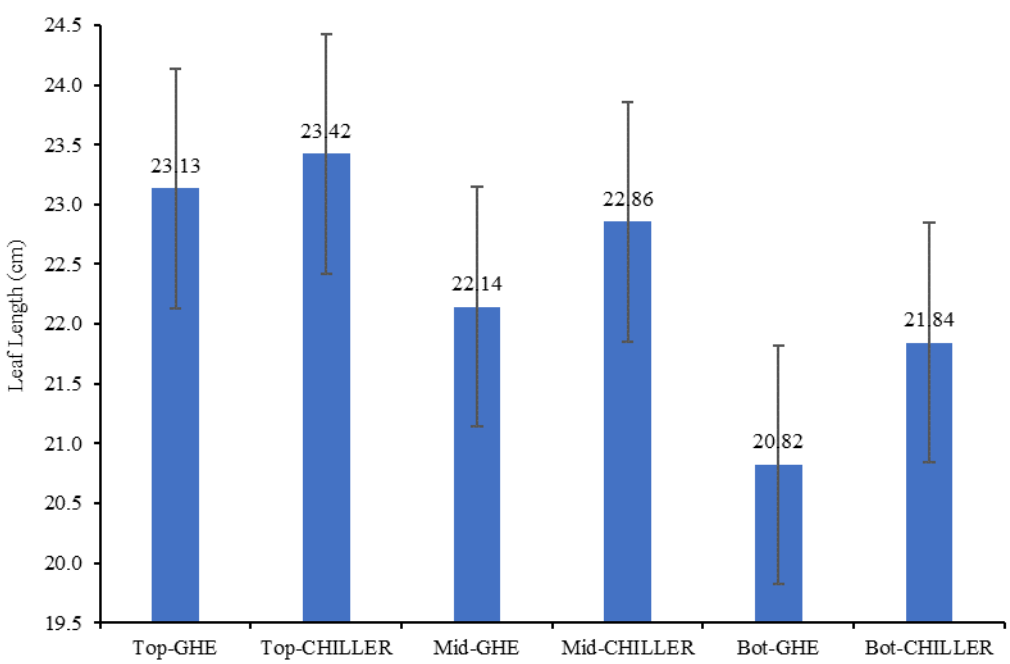
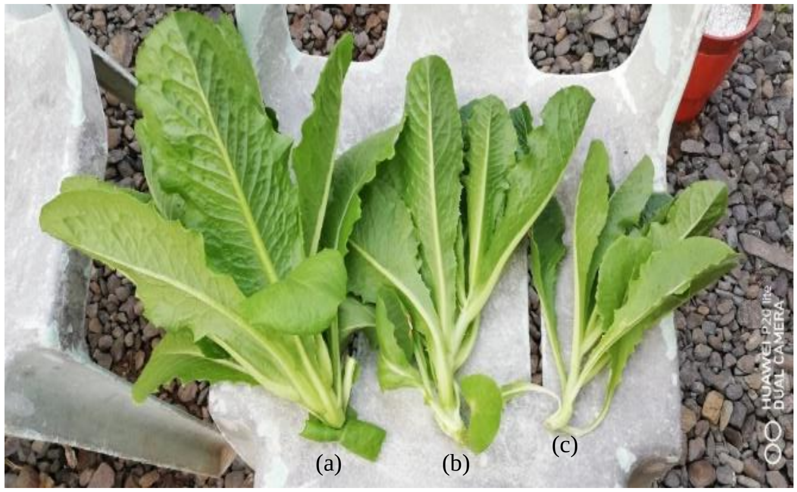



Figure 5 Length of lettuce as affected by different rootzone cooling methods and level of the tower




(a) top (b) middle (c) bottom

Figure 6 Leaf length, and width of lettuce harvested from the top (a), middle (b), and bottom (c) of the aeroponic tower

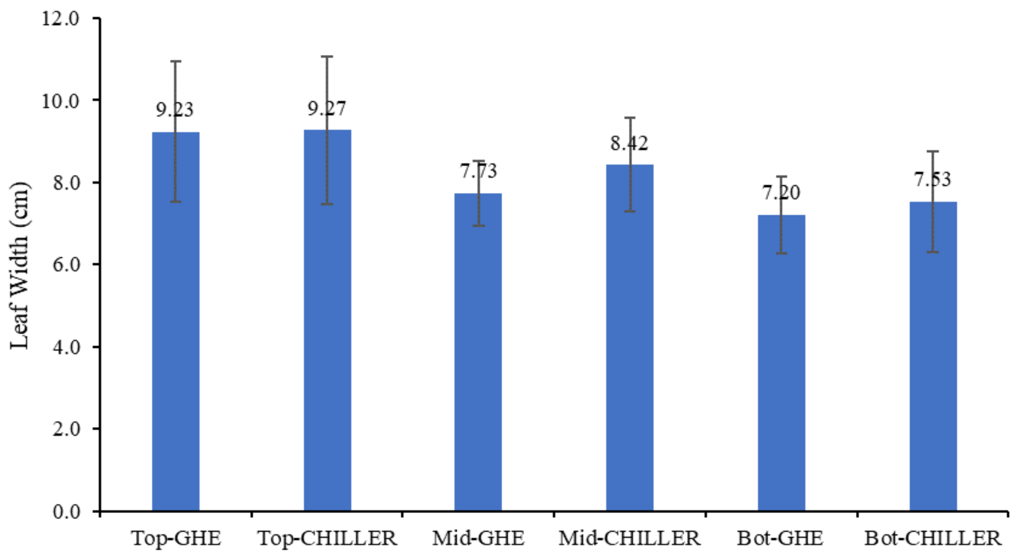



Figure 7 Leaf width of lettuce as affected by different rootzone cooling methods and the level of the tower

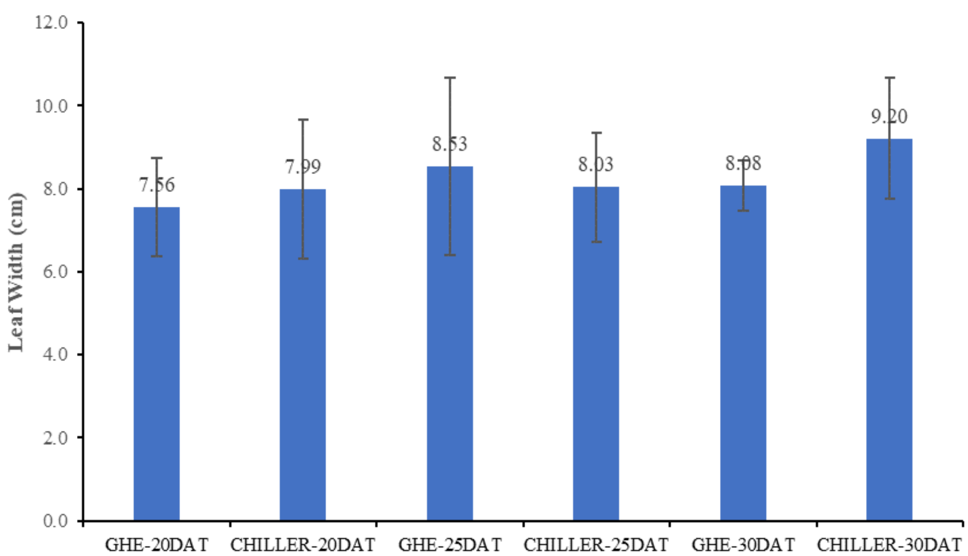



Figure 8 Leaf width of lettuce as affected by different rootzone cooling methods and harvest periods

### 3.4 Plant yield

The yield of lettuce plants as affected by different rootzone cooling methods, varying harvest periods, and layers of the tower is presented in Figures 9 and 10. The highest yield was 110 grams obtained on those plants harvested from the top layer of the tower and using the chiller, while 78.61 grams was obtained at 30 DAT using a chiller. While the least was obtained from those plants harvested from the bottom part of the tower using GHE with 28.64 grams, and at 20 DAT using a chiller for rootzone cooling with only 51.45 grams.

Analysis of variance showed significant differences between rootzone cooling methods, among harvest periods, among levels of the tower, and their interactions. Comparison among interaction means revealed that for the lettuce harvested with GHE as rootzone cooling method at 20 DAT, the yield from the top of the tower was significantly higher than harvested from the top layer using a chiller while those harvested from bottom and middle parts of the tower of GHE and chiller have no significant differences. Those harvested at 25 DAT, the yields in all parts of the tower between the two root zone cooling methods have no significant differences. However, those harvested at 30 DAT from the top of the tower using a chiller as a rootzone cooling method had significantly higher yields than those harvested from the top using GHE. The yield from the bottom and middle parts of the tower between the two root zone cooling methods has no significant differences.

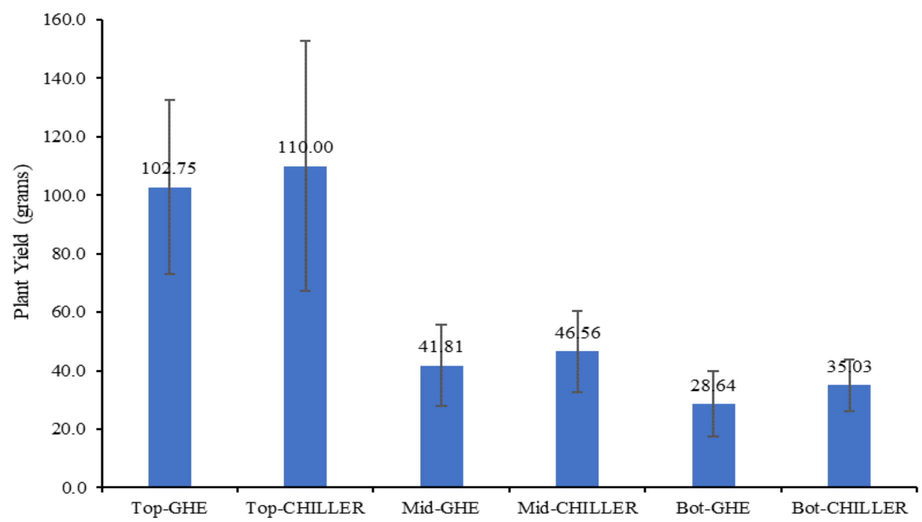



Figure 9 The yield of lettuce as affected by different rootzone cooling methods and the level of the tower

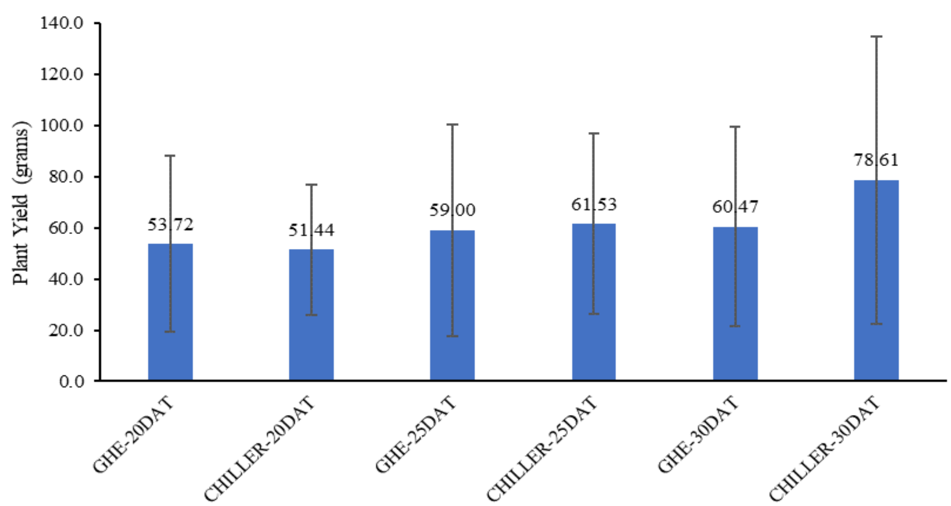



Figure 10 The yield of lettuce as affected by different rootzone cooling methods and harvest periods

Moreover, for the levels of the tower in each rootzone cooling method, plants harvested using GHE from the top of the tower at 20, 25, and 30 DAT have significantly higher yields than those harvested from the middle and bottom parts. Further, using the chiller as a rootzone cooling method, those harvested from the top layer of the tower at 20 and 25 DAT are significantly higher than those from the middle and bottom parts while at 30 DAT plants harvested from all layers are significantly different with each other with the top layer with a significantly higher yield.

In terms of the harvest period, a comparison among means revealed that the yield of harvest periods in each layer of the tower using GHE as a rootzone cooling method has no significant differences. However, using the chiller at 30 DAT the yield from the top layer is significantly higher than the yield from the top layers of 20 and 25 DAT while the yield at 20 and 25 DAT from all layers are not significantly different.

The top layer of the towers was closer to sunlight, while in the middle and bottom part, the plants on top were shading thus larger plants were grown on top of the towers compared to the middle and bottom part (Touliatos et al., 2016). In addition, there was a shading effect of the water tank brought about by its orientation above the greenhouse; also in between towers when plants started to develop to maturity. The tendency of the plants to catch good sunlight resulted in an elongated stem to outgrow competitors (Fiorucci and Fankhauser, 2017), so plants tend to reorient their growth toward a more favorable light environment (Ballare, 1999).

Generally, the combination with significantly higher yield was from those plants harvested at 30 DAT from the top layer of the tower that used a chiller as rootzone cooling method, followed by GHE of the same harvest period and layer of the tower. The same is true with the yield in terms of harvest weight per plant and harvest weight per area. The yield in producing lettuce in vertical aeroponics including all layers of the tower, using chiller as rootzone cooling method and harvested at 30 DAT had the highest yield than using GHE with the same harvest period. The yield in producing lettuce in vertical aeroponics including all layers of the tower, using chiller as rootzone cooling method and harvested at 30 DAT had the highest yield than using GHE with the same harvest period. Using a chiller as a root zone cooling method, the average yield of 78.61 grams per plant is equivalent to 7.55 kg m$^{-2}$ in an area with 2 towers m$^{-2}$ planted with 48 plants per tower. For GHE with an average yield of 60.47 grams per plant, the equivalent average yield is 5.80 kg m$^{-2}$ in the same area with the same number of towers. The yield in producing lettuce in vertical aeroponics including all layers of the tower, using chiller as rootzone cooling method and harvested at 30 DAT had the highest yield than using GHE with the same harvest period.

In using a chiller as a root zone cooling method, the average yield of 78.61 grams per plant was equivalent to 7.55 kg m$^{-2}$ in an area with 2 towers m$^{-2}$ planted with 48 plants per tower. For GHE with an average yield of 60.47 grams per plant, the equivalent average yield was 5.80 kg m$^{-2}$ in the same area with the same number of towers. The yield of producing lettuce in vertical aeroponics using any root zone cooling method was much higher compared to the conventional method of producing lettuce. According to DA-BPI (2016), with a planting distance of 30 cm between hills and rows and 3 rows per meter width of each plot, density was only at 9 plants m$^{-2}$ produced a kilo of lettuce considering that one kilo is approximately 4 to 8 plants, with an average yield of 166 grams per plant.

While the yield per plant was higher when using the conventional method of planting, it was the yield m$^{-2}$ that is a better index, and the significantly higher yield m$^{-2}$ on the plants harvested at 30 DAT and using a chiller as rootzone cooling method proved to be far more superior than the rest of the interaction means.

### 3.5 Economic analysis

Total fixed capital investment for the greenhouse with GHE and chiller were $3055.58 and $3267.22, respectively, while potential gross income was $5200.68 and $6756.58 for GHE and chiller, respectively (Table 1). Moreover, the assumed projected annual cost charges that included fixed costs and variable costs for GHE and chiller were $4040.11 and $5711.37, respectively. Results of cost and return analysis showed that in using the GHE, the average annual net income was $1160.56 while when the chiller was used average net annual income was $1045.21.

**Table 1 Potential annual production of Romaine lettuce using GHE and Chiller as rootzone cooling methods for 6m × 3m production area**

| PRODUCTION | T1 (GHE) | T2 (Chiller) |
|---|---|---|
| Number of aeroponic towers | 36 | 36 |
| Number of plants per tower | 48 | 48 |
| Total number of plants | 1728 | 1728 |
| Average yield per plant, gms | 60.5 | 78.6 |
| Total yield, kg/cropping | 104.54 | 135.82 |
| No. Cropping $yr^{-1}$ | 11 | 11 |
| Total Annual Yield, kg $yr^{-1}$ | 1149.98 | 1494.03 |
| Cost per kg, $ | 4.52 | 4.52 |
| POTENTIAL GROSS INCOME, $ $yr^{-1}$ | 5200.68 | 6756.58 |

Note: $1= 55.28 (July 2023)

Return on investment and payback period was 42% and 2.41 years, respectively for GHE; and 34% and 2.97 years, respectively for chiller. At a fixed annual yield of 1149.98 kg, the breakeven price in lettuce production using GHE as rootzone cooling method was $3.51 per kg.; while for Chiller, at a fixed annual yield of 1494.03 kg, the breakeven price was computed at $3.82 per kg. Profit started when the market price was more than the breakeven cost at a constant annual yield.

Economic viability in lettuce production using the two root zone cooling systems was comparable considering the financial indicators. However, using GHE as the root zone cooling method proved to be better in terms of fixed and operating costs and annual net income compared to using a chiller. The assumed production area was only 18 $m^2$. Assuming a linear increase in total operating costs when the production area was increased, a 100 $m^2$ production area using GHE as rootzone cooling method and harvesting at 30 DAT gave a potential annual net income of $6,447.56.

## 4 Conclusions and recommendations

The root zone cooling system using GHE and chiller are technically viable in the production of green-leaf Romaine lettuce. It reduces the temperature of nutrient solution before it reaches the root zone area of the plant providing lower rootzone temperature compared to ambient temperature in a tropical environment.

The growth of lettuce in vertical aeroponics using the rootzone cooling technology differs on the kind of rootzone cooling method, location in the tower, and harvest period. Longer and broader leaves and higher yields were observed using the chiller that was harvested from the top of the tower at 30DAT. Therefore, in terms of plant growth, the best combination of factors that produced better growth in lettuce were those using a chiller as a rootzone cooling method, located on the top portion of the tower and harvested at 30 DAT.

The application and utilization of rootzone cooling preferably the GHE in the production of green-leaf Romaine lettuce under tropical greenhouse conditions and harvested at 30 DAT is highly recommended under Philippine condition. To further improve the results of this study and for future adoption, the following are recommended:

Orientation of the greenhouse should be considered in such a way that no sunlight obstruction and shading will happen.

1. Distance of every tower should be crop-specific to avoid shading among plants considering the canopy coverage of the leaves.

2. Design a greenhouse that will further minimize the increase in air temperature.

3. Insulate the aeroponic towers to minimize heat transfer.

4. An alternative source of power can be adapted to

reduce power consumption.

5. Different high-value crops can be used to investigate the system's productivity.

6. Further study on suitable pressure, droplet size, and misting interval for lettuce to improve the continuous availability of nutrients and water in aeroponics.

7. Planting interval per layer of the tower can be adopted to avoid shading on plants in the lower part of the tower.

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