

Original Research Article

Effects of Root Zone Cooling on *Lactuca Sativa* Cultivation Under Roof Top Garden Structure in Tropical Climatic Conditions

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Abstract: A rooftop garden structure was installed on top of a 20-foot freight container plant factory in MARDI Serdang, Selangor. The rooftop garden consists of three major components: a rain shelter, a reticulated hydroponic growing system via Nutrient Film Technique (NFT), and a chiller system to chill and control the nutrient-water temperature in the fertiliser tank. *Lactuca sativa* was cultivated using root zone cooling, with a hydroponic setup at ambient temperature as a control to study the root zone cooling system (RZC) on the crop yields in the tropics. The weight of crop, root, leaf width and leaf numbers of *Lactuca sativa* have been selected as yield parameters, recorded, and analysed. From the results, all the growing parameters performance for *Lactuca sativa* grown in the root zone cooling method were found to be better than control. For yield parameters performance, *Lactuca sativa* grown in control was better than the root zone cooling method. The yield weight for *Lactuca sativa* cultivated as control is higher than the RZC system by 39.4%, ranging from 36.69(39.04 g as control) and 20.59(23.66 g) RZC method. Roots weight for *Lactuca sativa* cultivated as a control method is better than RZC by 14.1%, ranging from 5.73–6.22 g using control) and 4.69–5.34 g by using RZC, respectively. The number of leaves for *Lactuca sativa* cultivated as a control method is more than RZC by 26%, ranging from 14–15 as control and static at 11 using the RZC system. The leaves dimension for *Lactuca sativa* cultivated as control is more significant than RZC by 48%. The *Lactuca sativa* leaves dimension cultivated as a control method is from 580.35(670.27 cm²), while RZC is from 318.68–348.45 cm².

Keywords: root zone cooling; top roof garden; *Lactuca sativa*; tropics

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1. Introduction

Today, 54% of the world's population lives in urban areas, and the scenario is expected to increase to 66% by 2050 (United Nations, 2014). Rapid urbanisation and urban growth are causing massive demand on urban food supply systems. Moreover, many countries worldwide face problems like rapid decreases in agricultural land and increased temperatures due to human activities. Urban agriculture or farming is promoted as a potential solution to these problems (Smit, Nasr & Ratta, 2001). As food is grown locally, there is no need to import foods from other countries to reduce imports bills. Rooftop farming can reduce the temperature of roofs and the surrounding air that contribute to overall cooling a local climate (RIES, 2014) and help reduce the urban heat island effect (Hui, 2011). Roof farms can also absorb carbon emissions and noise (Dubbeling, 2014, Hui, 2011). Rainwater is captured and absorbed by the plants, and the overflowing impact on infrastructure is reduced (RIES, 2014). Rooftops filled with vegetation can be an excellent place for agro-tourism.

Farming on the rooftop of the buildings in urban areas is usually done using green roofs, hydroponics, organic, aeroponics, or container gardens (Asad & Roy 2014). A common problem when planting crops on rooftops is that it is most exposed to direct sunlight all day in the country's tropical conditions. Direct exposure to sunlight will increase ambient temperatures inside the crop protection structure, thus will increase the fertiliser temperature inside the water tank and hydroponic growing container. This will result in changes in EC, pH and ultimately affect fertilizer quality and plant growth.

In addition to temperature, He *et al.* (2002) and Bubel (2007) recommended that different plants thrive well under different water temperature regimes. When the water temperature drops below the optimum levels needed for crop growth, various modifications to the growth medium are essential to sustain the plant growth (Santarius, 2004). In this study, the root zone cooling system was developed to control and monitor the temperature of fertiliser in the fertiliser tank. The root zone cooling system is where the fertiliser tank is chilled down using a cooling coil to a targeted temperature according to the crop growth requirement needs. The chilled fertiliser will flow to the hydroponic growing container, and the temperature will be controlled using a solenoid valve. He and Lee (1998) studied the growth and photosynthetic characteristic of lettuce (*Lactuca sativa*) grown under fluctuating hot ambient temperatures to manipulate cool root zone temperature. According to the findings, lettuce grew fertile in extreme conditions when its roots were manipulated to meet specific crop growing requirements such as soil/root zone temperature and moisture content.

The hydroponic root zone cooling system (RZC) under the rooftop garden consists of three major components: the crop protection structure, the vertical farming system using a nutrient film technique (NFT) hydroponic crop grow trays, and the root zone cooling system itself. Among these devices, the chiller consumes the highest energy of the HRZC system. The consumed energy is related to loads of the system. It is necessary to determine the precise

minimum power of the chiller to reduce the production cost. The fertiliser concentration (EC) distribution studies on the NFT hydroponics root zone cooling (HRZC) system for *Lactuca sativa* cultivation on rooftop garden under the influence of water temperature, air temperature, relative humidity (RH), and ambient carbon dioxide (CO₂) was investigated. The study aims to evaluate *Lactuca sativa* growth performance using a hydroponic root zone cooling system under a rooftop garden in the tropics by analysing growth parameters such as yield weight, roots weight, leaf numbers, and leaf dimensions.

2. Materials and Methods

2.1 Roof Top Garden Structure

The study was conducted at Engineering Research Centre, Malaysian Agricultural Research and Development Institute (MARDI) in Serdang, Selangor, Malaysia. The rooftop garden was developed on top of the mini scaled plant factory, which is built from a used container with a size of 20 ft long and 10 ft wide (Figure 1). The rooftop garden uses a rain shelter as a crop protection structure, and the vertical farming system uses an NFT hydroponic growing container.



Figure 1. Rooftop garden structure



Figure 2. Chiller system for root zone cooling

2.2 Hydroponic Root Zone Cooling System (HRZC)

HRZC was developed by integrating a 2.5 hp chiller system that can control the fertiliser temperature inside the fertiliser tank and NFT hydroponic crop grow trays (Figure 2). The water-dissolved nutrient was chilled down to 10 °C via a chilling coil (Figure 3) and delivered using a 0.5 hp water pump to the NFT channels, which is 10 m long and vertically arranged at 4 m long each level at the wall of the rooftop garden structure (Figure 4). The water-dissolved nutrient temperature inside the 10 m length of the NFT channels was controlled between 15–25 °C using a valve and flow rates between 5–10 m³/s. The chiller was operated for 12 hours from 7.00 a.m. till 7.00 p.m.

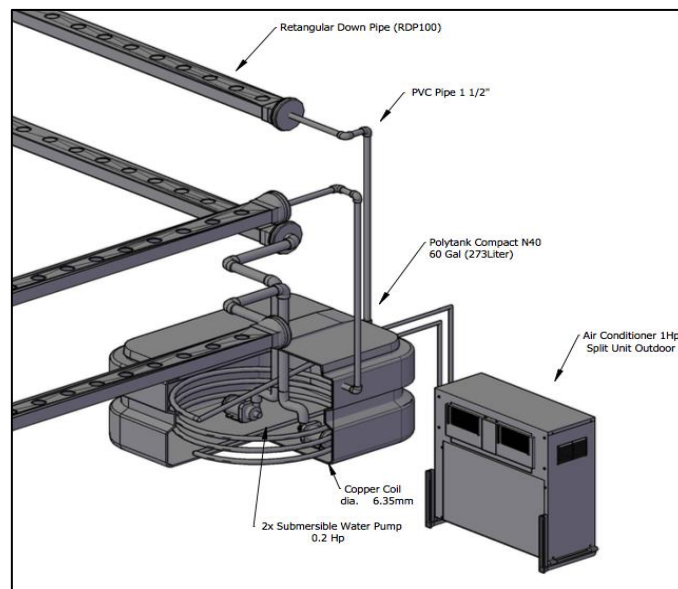


Figure 3. Chiller coil inside the water tank

2.3 *Lactuca Sativa* Cultivation

Lactuca sativa was planted in reticulated NFT hydroponics grow trays (0.2 m wide, 0.1 m thick, and 10 m long) in a 4-level stack attached to the wall of the rooftop garden structure. The nutrient-water level inside the growing NFT channel was maintained at 0.8 m deep by controlling the inlet pipe valve opening to allow nutrient uptake by crop roots. The crop spacing was 0.1 m, and a total length of 36 m NFT grow tray can accommodate near 360 crops. After three weeks of seeding and germination in the nursery, *Lactuca sativa* was transplanted under the rooftop garden. The crops were transplanted and grown inside the structure for five weeks before harvest. For control, a similar NFT grows tray system without a nutrient water chiller was used to grow *Lactuca sativa* at ambient temperature (Figure 4). For control, the crop spacing was 0.1 m, and a total length of 15 m NFT grow tray can accommodate near 150 crops.



Figure 4. *Lactuca sativa* cultivation under rooftop garden

2.4 Data Collection

A total of 50 from 400 *Lactuca sativa* cultivated with both methods were selected as samples. The growth parameters such as leaf number and leaf dimension were collected for *Lactuca sativa* cultivated in the RZC system and controlled for four hours daily. Meanwhile, yield parameters such as yield weight and roots weight are recorded after the crop is harvested.

2.5 Data Analysis

The data obtained were subjected to descriptive statistics, analysis of variance (ANOVA), and correlation analysis. The statistical analysis was carried out using SAS statistical software (Version 9.4, SAS Institute, USA).

3. Results

3.1 *Lactuca Sativa* Growth Performance Analysis for RZC System and Control.

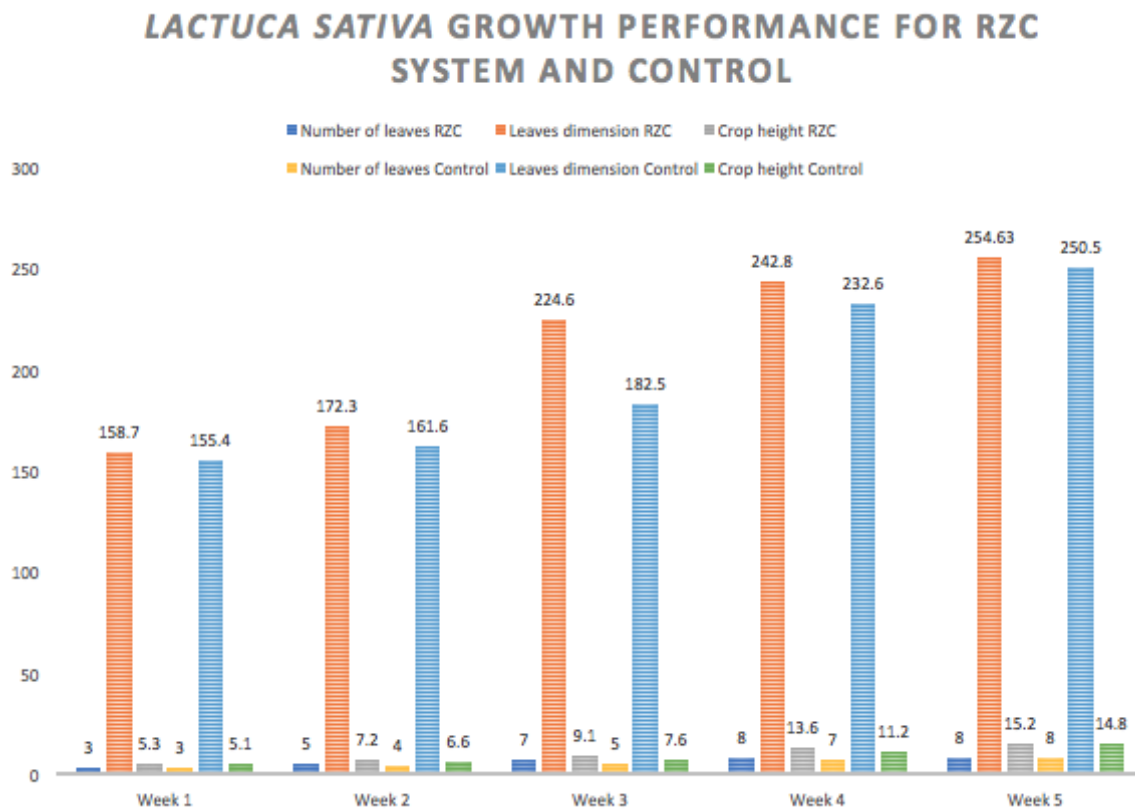


Figure 5. *Lactuca sativa* number of leaves dimension (cm²) and height comparison (cm) by using RZC system and control for five weeks after transplanting

Figure 5 demonstrates the *Lactuca sativa* growing performance using the RZC system and control for five weeks after the crops were transplanted from the nursery to the rooftop garden structure. The number of leaves for crops cultivated using the RZC system is similar to those cultivated by control at the first week. However, from week two to week four, the number of leaves of crops cultivated via the RZC system is more significant than control and remains similar again at week five. The range of *Lactuca sativa* leaves cultivated by the RZC system and control is from 3–8.

The leaves dimension for *Lactuca sativa* cultivated via the RZC system is more significant than control from week one to week five. The range of *Lactuca sativa* leaves dimension for the RZC system is from 158.7 cm²–254.63 cm², while control ranges from 155.4 cm²–250.5 cm². The heights for *Lactuca sativa* cultivated via the RZC system are also better than control from week one to week five. The range of *Lactuca sativa* heights for the RZC system is from 5.3 cm–15.2 cm, while control ranges from 5.1 cm–14.8 cm.

3.2 Crop Yield Performance Comparison for *Lactuca Sativa* Cultivated via RZC System and Control.

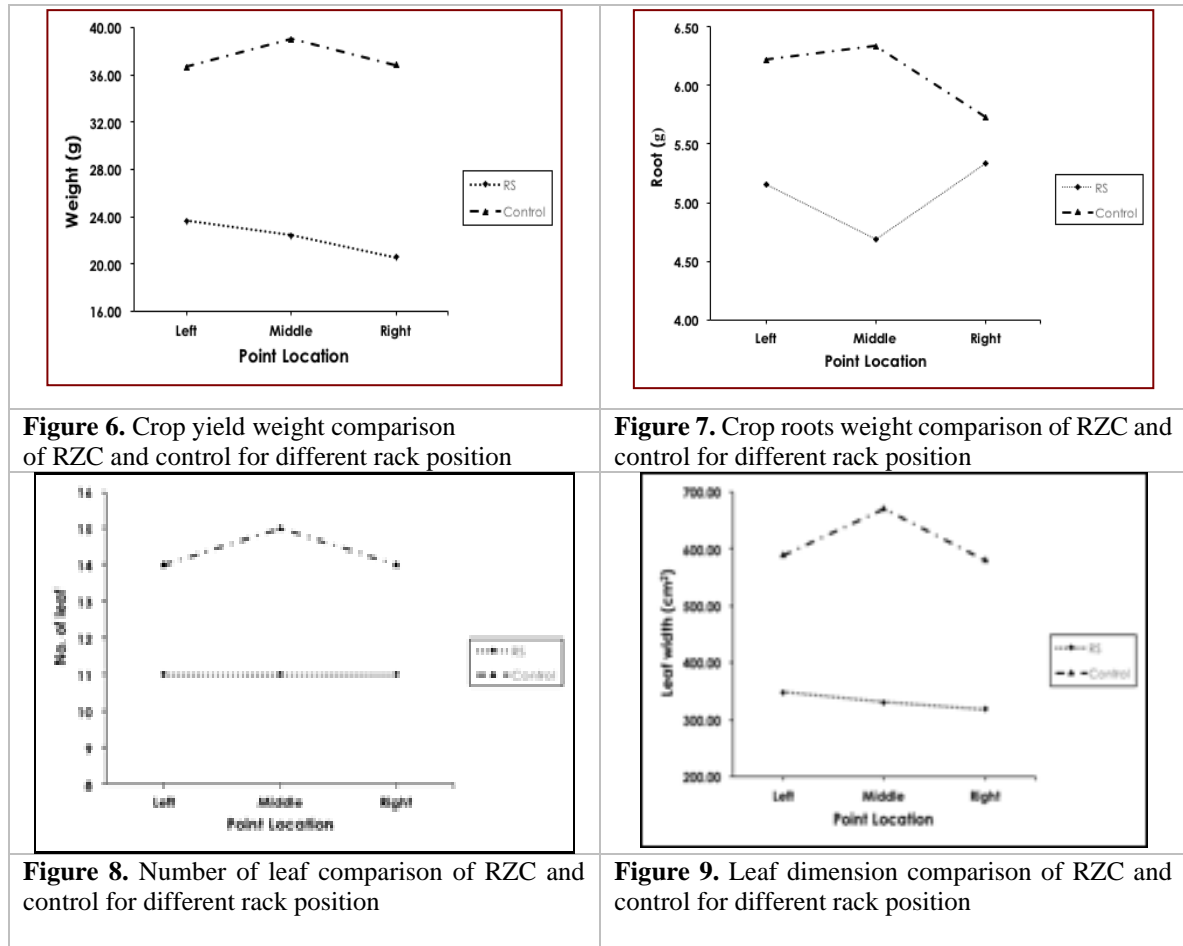


Figure 6 illustrates the weight of *Lactuca sativa* yield cultivated via RZC and control for three points of planting rack location at the left, middle, and right under the rooftop garden structure. The line graph shows that the yield of *Lactuca sativa* cultivated as control is more than RZC for all three points of planting rack location. The range of *Lactuca sativa* yield weight cultivated as control is from 36.69–39.04 g, meanwhile by using RZC is from 20.59–23.66 g. The weight fluctuated for control and decreased for the RZC method, ranging from 20.59–39.69 g, respectively.

Figure 7 shows the weight of *Lactuca sativa* roots cultivated via RZC and control for three points of planting rack location at the left, middle, and right under the rooftop garden structure. The graph shows that the roots for *Lactuca sativa* cultivated as control are heavier than RZC for all three points of planting rack location. The range of *Lactuca sativa* roots weight cultivated using control is from 5.73–6.22 g, RZC is from 4.69–5.34 g. The root fluctuated for both the RZC method and control, ranging from 4.69–6.22 g, respectively.

Figure 8 demonstrates the number of *Lactuca sativa* leaves cultivated via RZC and

control for three points of planting rack location at the left, middle, and right under the rooftop garden structure. The graph shows that the number of leaves for *Lactuca sativa* cultivated as control is more than RZC for three points of planting rack location. The range of *Lactuca sativa* number of leaf cultivated using control is from 14–15, using RZC is static at 11 respectively. The leaf fluctuated when cultivated using control and remained the same for RZC ranging from 11–15, respectively.

Figure 9 shows the *Lactuca sativa* leaf dimension cultivated via RZC and control for three points of planting rack location at the left, middle, and right under the rooftop garden structure. The graph shows that the leaf dimension for *Lactuca sativa* cultivated as control is more significant than RZC for three points of planting rack location. The range of *Lactuca sativa* leaf dimensions cultivated using control is 580.35(670.27 cm², using RZC is 318.68–348.45 cm² respectively). The leaf dimension fluctuated using control and decreased significantly for RZC ranging from 318.68–670.27 cm², respectively.

3.3 Pearson Correlation Coefficients Between the Parameters for RZC System and Control

	Weight	Root	Shoot	No. of Leaves
Root	0.514*			
Shoot	0.919*	0.592*		
No. of Leaves	-0.271*	-0.020	-0.191	
Leaves Width	0.883*	0.569*	0.938*	-0.170

Figure 10. Pearson correlation coefficients parameters for RZC System

	Weight	Root	Shoot	No. of Leaf
Root	0.581*			
Shoot	0.901*	0.666*		
No. of Leaf	0.669*	0.362*	0.713*	
Leaf Width	0.872*	0.444*	0.877*	0.810*

Figure 11. Pearson correlation coefficients parameters for the conventional hydroponic method

Figure 10 and 11 shows that the growth of *Lactuca sativa* was highly correlated with shoot, weight, and leaves width for both crops cultivated using RZC system and control. From the graph, * means the correlations are significant at P -value is less than 0.05. For the RZC system, the shoot was highly correlated to the weight of $r = 0.919$, with a P -value of less than 0.05. Meanwhile, leaves width was highly correlated with shooting where $r = 0.938$, which is P -value is less than 0.05. For control, the shoot was highly correlated to the weight, which $r = 0.901$, P -value is less than 0.05, and leaves width was highly correlated with shooting where $r = 0.877$, P -value is less than 0.05.

4. Discussions

The effect of root zone temperature is more significant on crops root growth, especially in the early stage of crop development (Mohammud *et al.*, 2012). Figure 6 shows that when *Lactuca sativa* cultivated using the RZC method grows rapidly and quickly compared to the crop harvested using the control at the early week of crop development. However, extreme root zone temperature manipulation can cause excessive vegetative growth, flower abscission, and poor fruit set. Thus, it is essential to consider the crop requirements before planning for the cooling technique (Mat Sharif, 2006).

Figures 7, 8, 9, and 10 illustrate that crops grown in control at 33 °C demonstrated greater yield weight, roots weight, leaf numbers, and leaf dimension production. Results from Chito and Jaypee (2015) also showed that lettuce tolerated an environment beyond the optimal and remained productive throughout the six growing seasons even at the temperature of 25 to 35 °C and relative humidity of 50 to 88 %. In this study, crops cultivated as control are located in the middle of the roof top garden structure and it was protected from direct hot sunlight by crops cultivated in the wall. Hence, this explains why the result for yield is better by using control compared to the RZC system. Differences in production temperatures resulted in an inverse relationship between root and shoot development (Sublett *et al.*, 2018). The current study results diverged from the expected effects of heat stress on lettuce and other crops. The degree to which lettuce can tolerate adverse temperatures is known to vary significantly among cultivars.

The growth of *Lactuca sativa* was highly correlated with shoot, weight, and leaves width for both crops cultivated using the RZC system and control. The formation of compact heads and the growth and development of root and shoot were affected by root zone temperature (He & Lee, 1998). Instead of cooling the aerial environment, the root zone cooling system has become an alternative method in the control environment technique for crop production. This method shows significant results in increasing plant growth where the results show that in the first five weeks, crops cultivated using RZC is rapidly grow compared to control. Gosselin and Trudel (1984) stated that crop productivity could be maintained under fluctuate ambient temperature when root zone temperature is controlled. Although the shooting environment of all plants was identical, the root zone cooling temperature has some significant effects on roots nutrient intake ability.

5. Conclusion

The study found that the growing performance of *Lactuca sativa* cultivated using RZC has a better result than control when growing under the rooftop garden in the tropics. Meanwhile, the yield performance for *Lactuca sativa* growth as control has a better result than the root zone cooling method. This shows that the RZC method can decrease the production time of the lettuce when cultivating under the rooftop garden in the tropics.

Meanwhile, the control can produce a better yield. Thus, this study provides a range of information that could be required to evaluate the NFT root zone cooling system for crop cultivation under the rooftop garden.

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Conflicts of Interest: The authors declare no conflict of interest, and also the funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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