

*Original Research Article*

## Fertiliser Concentration Detection by Means of Hydroponic Root Zone Cooling System on Roof Top Garden for *Lactuca sativa* Cultivation

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**Abstract:** Nutrient film technique (NFT) is a hydroponic technique, whereby a very shallow stream of water containing all the dissolved nutrients required for plant growth is re-circulated past the bare roots of plants in a watertight gully, also known as channels. Problems commonly associated with NFT hydroponic system such as water temperature, can easily increase under direct sunlight in the tropics region, especially in the roof top garden, that can affect the quality of fertiliser used to cultivate the crop. Therefore, a study to develop a cooling system for NFT hydroponic technique is significant to control the water-dissolved nutrient temperatures suitable for crop growth. This paper highlights the studies conducted on fertiliser concentration distribution in the NFT hydroponics root zone cooling (HRZC) system for *Lactuca sativa* cultivation on roof top garden under the influence of water temperature, air temperature, relative humidity and ambient carbon dioxide. The fertiliser concentration distribution is determined by taking the electric conductivity (EC) reading of the fertiliser flowing along the NFT channels within three targeted points (left, middle, right) at four different height levels of the cultivation beneath the roof top garden. The EC readings of the fertiliser remained steady, except for the tank along the levels from left, middle and right locations ranging from 1.64–1.66  $\mu\text{S}$ . The water temperature, air temperature, relative humidity and ambient carbon dioxide fluctuated along these three points ranging from 20.50–22.80°C, 31.39–32.23°C, 67.06–68.65%, and 459.39–472.13 ppm, respectively. It was found that under the influence of those environment parameters and NFT root zone cooling system with different level and height, the fertiliser concentration distribution from point to point of data taken is not significantly different along the NFT channels. This finding is significant that integration of NFT root zone cooling system is an alternative to *Lactuca sativa* cultivation on roof top garden, despite the affecting surrounding temperature that may affect the quality and quantity of fertiliser and crops cultivation. This technique can be extended for the cultivation of other hydroponic vegetables, rice and flowers and promote the culture of roof top farming in the society to avoid the highly polluted soil on the ground environment that may bioaccumulate into the plant system that may ended up as a health threat to fellow consumers.

**Keywords:** fertiliser concentration; NFT hydroponic; root zone cooling; roof top garden; environmental parameters

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## 1. Introduction

Malaysia Agriculture Research and Development Institute (MARDI) has developed several cooling techniques in the greenhouse to increase the production of the temperate crop in the lowland. Research has been done to explore the alternative technology of cooling such as root zone cooling system, misting fan, evaporative pad and ventilation fan which can reduce the production cost (Ahmad Syafik *et al.*, 2010). This root zone cooling system can be adapted to the hydroponics cultivation method, which enables the water-dissolved nutrient temperature to be controlled. It was reported that the effect of root zone temperature is greater on root growth especially in the early stage of crop development (Mohammud *et al.*, 2012).

Extreme root zone temperature manipulation can cause excessive vegetative growth, flower abscission and poor fruit set. Thus, it is important to consider the crop requirements before planning for cooling technique (Mat Sharif, 2006). In this study, the hydroponic root zone cooling (HRZC) system was developed to cultivate high-value vegetables in tropics and to determine the effects of HRZC on crops growth and yields. Among the many varieties of high-value vegetables in Malaysia, Lettuce, scientifically named as *Lactuca sativa* varieties has been chosen as a selected vegetable in this study due to its affordable price in Malaysian markets, which is between RM 6/kg and RM 8/kg. Moreover, *Lactuca sativa* also known and popular because it can be grown easily with the hydroponics system besides having simple maintenance procedure.

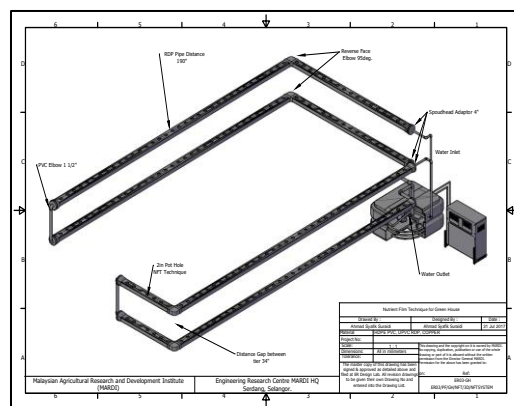
The hydroponic root zone cooling system includes the chiller, cooling water pump, and hydroponic growing container. Among these devices, the chiller consumes most power of the HRZC system. The consumed energy is related to the loading of the system and it is necessary to determine the precise minimum power of the chiller to be used in order to reduce the production cost. There were several literatures discussing how to optimise the chiller loading, Braun *et al.* (1989) proposed the equal loading distribution (ELD) method. This method was established under the same operating characteristic of the chiller. Due to the different operating characteristic of the chiller, Braun *et al.* suggested that the power consumption of the chiller was correlated with load of air conditioner, cooling water return temperature and chiller water supply temperature. The fertiliser concentration (EC) distribution studies on the NFT hydroponics root zone cooling (HRZC) system for *Lactuca sativa* cultivation on roof top garden proven to be highly influenced by water temperature, air temperature, relative humidity (RH) and ambient carbon dioxide (CO<sub>2</sub>) was investigated.

The objective of the study is to evaluate the HRZC system performance in distributing and controlling water-dissolved nutrient temperatures to meet crop-root requirement needs.

## 2. Materials and Methods

### 2.1 Hydroponics Root Zone Cooling System Development

The study was conducted at Engineering Research Centre, Malaysian Agricultural Research and Development Institute (MARDI) in Serdang, Selangor, Malaysia with latitude N 2° 59' 51.4392", longitude E 101° 41' 26.2284" and 37.8 m above sea level (Diyana, 2009). HRZC was developed by the integration of 1 HP chiller system that can control the water-dissolved nutrient temperature inside the NFT channels (Figure 1). The water-dissolved nutrient was chilled till 10°C and flowed using a 0.5 HP water pump to the NFT channels, which was 10 m long and vertically arranged at 4 m long each level at the wall of the roof top garden structure. The water-dissolved nutrient temperature inside the 10 m length of the NFT channels at different heights levels was controlled between 15–25°C using a pipe valve and water with velocities between 5–10 m<sup>3</sup>/s. The chiller was switched on for 12 hours from 7.00 a.m. in the morning till 7.00 p.m. in the evening.



**Figure 1.** Systems schematic drawing.

### 2.2 *Lactuca sativa* Cultivations

*Lactuca sativa* was planted in a Nutrient Film Technique (NFT) hydroponics channels of 0.2 m wide, 0.1 m thick and 10 m long at each four levels that were vertically arranged on the wall of the roof top garden structure. The water level inside the growing NFT channel was 0.8 m deep, which can be reached by the crop roots. The crop spacing was 0.1 m, and for 10 m long of growing NFT channel that can accommodate near 300 crops. *Lactuca sativa* was transplanted under the roof top garden after three weeks of seeding and germination in the nursery. The crops were transplanted and grow inside the structure for three weeks before being harvested.

### 2.3 Data Collection

The readings of water-dissolved nutrient EC and temperature for 10 points i.e. from H1.1 to H1.10 along the NFT channels at different heights of cultivation under the roof top garden were collected for four weeks between 8.00 a.m. and 5.00 p.m. in order to determine the fertiliser concentration distribution along the growing NFT channels. The ambient temperature, relative humidity (RH) and carbon dioxide reading was also collected at the same interval and time to study the correlation between the ambient parameters and fertiliser concentration distribution temperature long the NFT channels under the roof top garden cultivation.

## 3. Results and Discussions

### 3.1 Effect of Level on the Environmental Parameters

Table 1 shows the EC, fertiliser temperature ( $T_{\text{water}}$ ) and environmental parameters ( $T_{\text{air}}$ , RH,  $\text{CO}_2$ ) subjected to three-point locations for four levels of *Lactuca sativa* cultivation at different height beneath the roof top garden. The EC readings were not significantly different from point to point along the growing NFT channels with different height of crop cultivation except for the water tank, ranging from 1.64–1.66  $\mu\text{S}$ . The water temperature fluctuated along the levels for left, middle and right locations ranging from 20.50–22.80°C, respectively. The air temperature fluctuated along the levels for left, middle and right locations ranging from 31.39–32.23°C, respectively. The RH fluctuated along the levels for left, middle and right locations ranging from 67.11–71.06%. On the other hand, the carbon dioxide fluctuated along the levels for left, middle and right locations ranging from 459.39–472.13 ppm, respectively. In this case, all parameters (EC, water temperature, air temperature, RH and  $\text{CO}_2$ ) were not significantly different with the level and point location.

**Table 1.** Environmental parameters subjected with three point locations at different levels for reticulation system.

Level	Parameter	Point location		
		Left	Middle	Right
A1	EC	1.65±0.01 <sup>a</sup>	1.65±0.01 <sup>a</sup>	1.64±0.01 <sup>a</sup>
	$T_{\text{water}}$	20.66±0.99 <sup>a</sup>	20.83±1.05 <sup>a</sup>	20.50±1.04 <sup>a</sup>
	$T_{\text{air}}$	31.85±0.74 <sup>a</sup>	31.79±0.67 <sup>a</sup>	31.50±0.76 <sup>a</sup>
	RH	69.47±2.41 <sup>a</sup>	68.83±2.24 <sup>a</sup>	70.03±2.33 <sup>a</sup>
	$\text{CO}_2$	468.13±4.40 <sup>a</sup>	458.00±3.31 <sup>a</sup>	460.00±3.53 <sup>a</sup>
A2	EC	1.66±0.01 <sup>a</sup>	1.66±0.01 <sup>a</sup>	1.65±0.01 <sup>a</sup>
	$T_{\text{water}}$	20.83±1.00 <sup>a</sup>	20.94±1.02 <sup>a</sup>	21.31±1.01 <sup>a</sup>
	$T_{\text{air}}$	32.18±0.74 <sup>a</sup>	31.99±0.66 <sup>a</sup>	31.96±0.75 <sup>a</sup>
	RH	67.11±2.40 <sup>a</sup>	68.89±2.19 <sup>a</sup>	69.16±2.21 <sup>a</sup>
	$\text{CO}_2$	464.25±3.82 <sup>a</sup>	468.38±3.55 <sup>a</sup>	468.63±3.73 <sup>a</sup>
B1	EC	1.65±0.01 <sup>a</sup>	1.65±0.01 <sup>a</sup>	1.66±0.01 <sup>a</sup>
	$T_{\text{water}}$	20.98±1.00 <sup>a</sup>	21.08±0.95 <sup>a</sup>	21.64±0.94 <sup>a</sup>

Level	Parameter	Point location		
		Left	Middle	Right
	T <sub>air</sub>	31.71±0.75 <sup>a</sup>	31.76±0.66 <sup>a</sup>	31.46±0.75 <sup>a</sup>
	RH	69.43±2.43 <sup>a</sup>	69.96±2.15 <sup>a</sup>	70.63±2.29 <sup>a</sup>
	CO <sub>2</sub>	465.25±3.56 <sup>a</sup>	462.50±3.44 <sup>a</sup>	459.38±4.02 <sup>a</sup>
B2	EC	1.65±0.01 <sup>a</sup>	1.66±0.01 <sup>a</sup>	1.65±0.01 <sup>a</sup>
	T <sub>water</sub>	21.41±0.91 <sup>a</sup>	21.48±0.87 <sup>a</sup>	21.35±0.87 <sup>a</sup>
	T <sub>air</sub>	32.19±0.74 <sup>a</sup>	31.91±0.66 <sup>a</sup>	31.83±0.75 <sup>a</sup>
	RH	68.16±2.38 <sup>a</sup>	68.98±2.15 <sup>a</sup>	69.24±2.34 <sup>a</sup>
	CO <sub>2</sub>	464.88±2.95 <sup>a</sup>	470.63±3.81 <sup>a</sup>	466.50±3.59 <sup>a</sup>
C1	EC	1.65±0.01 <sup>a</sup>	1.65±0.01 <sup>a</sup>	1.65±0.01 <sup>a</sup>
	T <sub>water</sub>	21.80±1.05 <sup>b</sup>	21.88±1.03 <sup>b</sup>	21.78±1.03 <sup>b</sup>
	T <sub>air</sub>	31.60±1.11 <sup>a</sup>	31.63±0.96 <sup>a</sup>	31.45±0.96 <sup>a</sup>
	RH	69.48±3.84 <sup>a</sup>	70.04±3.31 <sup>a</sup>	71.06±3.13 <sup>a</sup>
	CO <sub>2</sub>	464.50±3.48 <sup>a</sup>	465.63±4.47 <sup>a</sup>	465.38±5.47 <sup>a</sup>
C2	EC	1.65±0.01 <sup>a</sup>	1.65±0.01 <sup>a</sup>	1.65±0.01 <sup>a</sup>
	T <sub>water</sub>	21.60±1.03 <sup>b</sup>	21.86±0.99 <sup>b</sup>	22.44±1.00 <sup>b</sup>
	T <sub>air</sub>	32.20±1.09 <sup>a</sup>	31.91±0.96 <sup>a</sup>	31.63±0.97 <sup>a</sup>
	RH	67.24±3.75 <sup>a</sup>	69.18±3.39 <sup>a</sup>	69.09±3.20 <sup>a</sup>
	CO <sub>2</sub>	462.25±3.17 <sup>a</sup>	469.13±0.81 <sup>a</sup>	466.63±5.44 <sup>a</sup>
D1	EC	1.65±0.01 <sup>a</sup>	1.65±0.01 <sup>a</sup>	1.65±0.01 <sup>a</sup>
	T <sub>water</sub>	21.95±0.91 <sup>a</sup>	22.51±0.87 <sup>a</sup>	22.61±0.87 <sup>a</sup>
	T <sub>air</sub>	31.43±0.74 <sup>a</sup>	31.52±0.66 <sup>a</sup>	31.39±0.75 <sup>a</sup>
	RH	68.88±2.38 <sup>a</sup>	70.15±2.15 <sup>a</sup>	70.61±2.34 <sup>a</sup>
	CO <sub>2</sub>	464.00±2.95 <sup>a</sup>	472.13±3.81 <sup>a</sup>	462.25±3.59 <sup>a</sup>
D2	EC	1.65±0.01 <sup>a</sup>	1.66±0.01 <sup>a</sup>	1.65±0.01 <sup>a</sup>
	T <sub>water</sub>	22.80±1.05 <sup>b</sup>	22.68±1.03 <sup>b</sup>	22.58±1.03 <sup>b</sup>
	T <sub>air</sub>	32.23±1.11 <sup>a</sup>	32.19±0.96 <sup>a</sup>	31.60±0.96 <sup>a</sup>
	RH	67.36±3.84 <sup>a</sup>	68.13±3.31 <sup>a</sup>	68.91±3.13 <sup>a</sup>
	CO <sub>2</sub>	463.63±3.48 <sup>a</sup>	466.75±4.47 <sup>a</sup>	466.50±5.47 <sup>a</sup>
Tank	EC	1.53±0.03 <sup>a</sup>	1.53±0.03 <sup>a</sup>	1.53±0.03 <sup>a</sup>
	T <sub>water</sub>	22.45±0.85 <sup>b</sup>	22.45±0.85 <sup>b</sup>	22.45±0.85 <sup>b</sup>

\* Abbreviation of variables were EC: EC, T<sub>water</sub>: water temperature, T<sub>air</sub>: air temperature, RH: relative humidity, CO<sub>2</sub>: carbon dioxide. Different letters within the same column indicate statistical difference by the Tukey's test,  $P < 0.05$  for nine levels.

Furthermore, Chen *et al.* (2016) reported the growth of Boston lettuce and coral lettuce for germination with the nutrient solution circulating between the planting beds and storage tank with a pump in order to maintain the uniformity of the nutrient intake. An efficient hydroponic system governed by environmental factors that affected the crop growth, which was light intensity, EC, pH, temperature, humidity, CO<sub>2</sub> and others. (Amado *et al.*, 2016; Shamshiri *et al.*, 2018). In previous work, Hasegawa *et al.* (2014) reported the changes in CO<sub>2</sub> and temperature in relation to the growth of the plant samples. It was observed that plants cultivated at low temperature showed high photosynthesis rates compared to the plants cultivated at high temperature. Therefore, it can be noted that temperature was vital in the

plant growth and yield. Tamura *et al.* (2018) studied the phytochemical accumulation and yield of leaf lettuce in conjunction with various growth factors including temperature, EC and light intensity, in order to determine the efficiency of hydroponic system. From the findings, the ambient temperature at the roof top garden at all three points are within accepted value for *Lactuca sativa* cultivation, once the NFT channel is equipped with Hydroponic Root Zone Cooling system.

### 3.2 Effect of Time on the Environmental Parameters

Table 2 shows the environmental parameters subjected with three point locations at different time for the growing NFT channel. The fertiliser EC readings were not significantly different along the growing NFT channel for left, middle and right locations ranging from 1.58–1.67  $\mu\text{S}$ . But the fertilizer EC readings are significantly different for morning and afternoon. The optimal fertiliser EC decreased as temperature increased. The water temperature almost maintained the same throughout the recorded time for left, middle and right locations ranging from 18.79–24.73°C. On the contrary, the air temperature slightly decreased along the time for left, middle and right locations ranging from 24.82–25.94°C. The RH increased significantly along the time for left, middle and right locations ranging from 53.06–58.16%. The carbon dioxide slightly increased in the morning and fluctuated in the afternoon throughout the time for left, middle and right locations ranging from 361.60–381.45 ppm, respectively. It can be noted that all parameters can be influenced with the time as the temperature surrounding NFT channel differs as they are correlated to one another.

**Table 2.** Environmental parameters subjected with three point locations at different time for reticulation system.

Time	Parameter	Point location		
		Left	Middle	Right
Morning	EC	1.58±0.01 <sup>b</sup>	1.59±0.01 <sup>b</sup>	1.59±0.01 <sup>b</sup>
	T <sub>water</sub>	18.79±0.55 <sup>b</sup>	18.92±0.53 <sup>b</sup>	19.09±0.54 <sup>b</sup>
	T <sub>air</sub>	25.14±0.41 <sup>a</sup>	25.14±0.37 <sup>a</sup>	24.82±0.43 <sup>a</sup>
	RH	57.06±1.46 <sup>a</sup>	57.57±1.32 <sup>a</sup>	58.16±1.47 <sup>a</sup>
	CO <sub>2</sub>	379.48±1.55 <sup>a</sup>	380.38±1.94 <sup>a</sup>	381.45±2.38 <sup>a</sup>
Afternoon	EC	1.67±0.01 <sup>a</sup>	1.67±0.01 <sup>a</sup>	1.67±0.01 <sup>a</sup>
	T <sub>water</sub>	24.60±0.51 <sup>a</sup>	24.71±0.51 <sup>a</sup>	24.73±0.51 <sup>a</sup>
	T <sub>air</sub>	25.94±0.52 <sup>a</sup>	25.81±0.46 <sup>a</sup>	25.75±0.50 <sup>a</sup>
	RH	52.37±1.58 <sup>a</sup>	53.06±1.43 <sup>a</sup>	53.58±1.39 <sup>a</sup>
	CO <sub>2</sub>	363.90±2.51 <sup>b</sup>	366.25±2.04 <sup>b</sup>	361.60±1.39 <sup>b</sup>

\* Abbreviation of variables were EC: EC, T<sub>water</sub>: water temperature, T<sub>air</sub>: air temperature, RH: relative humidity, CO<sub>2</sub>: carbon dioxide. Different letters within the same column indicate statistical difference by the Tukey's test,  $P < 0.05$  at two different time periods.

### 3.3 Pearson Correlation Between EC, Temperature of Fertiliser Distribution and Environment Parameters

The Pearson correlation between EC, temperature of fertiliser distribution and environmental parameters *in the*NFT channel at the roof top garden is presented in Table 3. The results demonstrated there was a strong relationship between environmental parameters and fertiliser concentration parameters. Based on the result, the CO<sub>2</sub> was highly correlated to the air temperature ( $r = 0.953$ ). Among the environmental parameters values, the highest correlation was recorded between air temperature and water temperature ( $r = 0.965$ ). These observations showed the discrepancy in all environmental parameters that exhibited the importance of these parameters in affecting the quality of the fertiliser concentration for *Lactuca sativa* cultivation under the roof top garden structure, which was directly exposed with the fluctuated weather or ambient.

**Table 3.** Pearson correlation coefficients between environmental factors and fertilizer concentration parameters for growing NFT channel under roof top garden.

	EC	T <sub>water</sub>	T <sub>air</sub>	RH
T <sub>water</sub>	0.205			
T <sub>air</sub>	0.200	<b>0.965*</b>		
RH	0.347*	-0.195	0.817*	
CO <sub>2</sub>	0.470*	-0.159	<b>0.953*</b>	0.944*

Abbreviation of variables were EC: EC, T<sub>water</sub>: water temperature, T<sub>air</sub>: air temperature, RH: relative humidity, CO<sub>2</sub>: carbon dioxide. \* The means are significant at  $P < 0.05$ .

The findings from this research such as Electrical Conductivity from fertilisers present in the NFT channel, temperature of fertilizer distribution and environmental parameters namely, water temperature, air temperature, relative humidity and carbon dioxide are strongly correlated which have proven the validity of the result and accuracy with the previous literatures in the parameters required for crop quality and growth in hydroponic technique, especially at the roof top garden. In a research conducted by Baek *et al.* (2016), temperature and air flow stagnation were important for the plant cultivation in order to determine the crop quality and growth in a hydroponic system. Tamura *et al.* (2018) suggested that the growth and quality of vegetables cultivated using the hydroponic technique was influenced by the temperature, humidity, light source and fertiliser. Moreover, Lee *et al.* (2019) reported the growth of crisp-head lettuce by comparing the type of cultivar, temperature and light intensity. It was revealed that the growth of crisp-head lettuce was significantly influenced by temperature in low light intensity condition for all type of cultivars. In a similar study, Lee *et al.* (2013) investigated the productivity and quality of lettuce under artificial plant factory, indicating that low temperature conditions were applied to avoid tip-burn due to reduction of photosynthetic rates.

## 4. Conclusion

From the study, it was found that the fertiliser concentration distribution for growing NFT channels under the roof top garden for *Lactuca sativa* cultivations are not significantly different from different point of data taken either horizontally or vertically. The fertiliser EC and temperature reading were significantly different from time to time, which can be seen during the data taken in the morning and in the afternoon. The environmental parameters such as ambient temperature, RH and CO<sub>2</sub> have a significant correlation on EC and temperatures of fertilizer distribution under the roof top garden. Thus, this study provides a range of information, which could be required for the evaluation of NFT root zone cooling system for crop cultivation under the roof top garden.

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