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DEVELOPMENT AND EVALUATION OF A MODULAR HYDROPONICS WITH PELTIER COOLING SYSTEM FOR ROMAINE (*Lactuca sativa*) PRODUCTION

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Abstract

This study evaluated the quantitative performance of the fabricated modular hydroponics system integrated with a Peltier module as a rootzone cooling device to regulate and enhance the production of romaine lettuce. The experimental design fabricated and installed two treatment systems with identical modular hydroponics to compare the growth and yield results of conventional lettuce production without rootzone cooling (Treatment 1) and hydroponics with rootzone cooling (Treatment 2). The nutrient solution temperature was maintained between 20 to 22 ºC during daytime. Other water quality parameters including pH and electrical conductivity were also maintained within the recommended range during the 30 days growing period. The results of the statistical analysis using paired samples t-Test demonstrated significant differences at 5% level for yield performances. The analysis comparing the weight difference between the two treatments yielded a t-statistic of 2.654 with a p-value of 0.0139, where Treatment 2, significantly outperformed Treatment 1 in yield and efficiency. The final yield was 1390grams, this is significantly higher than Treatment 2, 1159grams. Economic feasibility yields a benefit-to-cost ratio of 1.85 and a return on investment of less than 2 years, justifying the P12,828.76 cost of initial investment. The results confirm that the integration of Peltier module in rootzone temperature management is a robust and economically viable strategy for maximizing the yield of romaine lettuce in modular hydroponics system.

Keywords *: modular hydroponics, rootzone cooling, Peltier module, romaine lettuce*

Introduction

Lettuce is considered to be one of the most important crops in the market that is used for salad, and since a lot of people have learned to appreciate the benefits that they can get from the green plants, especially the health benefits, lettuce has become popular and in demand in the markets. But lettuce production faces problems during its growing period in temperate areas of the Philippines. According to the Philippine Statistic Authority (PSA, 2021), the volume of lettuce production in Region III, increased from 1.86 cubic meters in the year 2018 to 7.02 cubic meters in the year 2019 to 7.58 cubic meters in the year 2020, representing an 8.0% change from the years 2019 to 2020. Due to the increase in demand for salad vegetables in the Philippines, lettuce nowadays has a high market potential, and since the demand for lettuce continues to increase, its continuous production is in need.

Planting lettuce in soil-based system is currently experiencing challenges such as natural disasters, climate change, and land infertility that are a product of using chemicals as well as pesticides (Nisha et al., 2018). Another problem is the weather conditions in the Philippines. Due to the tropical weather, growing lettuce in the lowland areas of the Philippines is seen to be impractical, yet the desire to produce is essential due to the rising demand (Capuno et al., 2014). Due to climate change, there are also threats in the form of rising temperatures, frequent dry periods, and the unpredictability of the weather patterns.

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These are the serious problems in conventional soil-based agriculture that make the production of lettuce a real challenge.
With these, alternative ways of planting might be considered, like the hydroponic system. Hydroponic farming may be one of the current alternatives that can meet the need for fresh, secure, and nutritious vegetables. The plant that uses the hydroponic system grows faster and bigger because receiving nutrients from its surroundings requires less energy. As water becomes scarce and vital as a source, the implementation of hydroponics as well as other water-saving methods for crop production is necessary nowadays and become more popular over time. Hydroponics requires far less water than soil farming (Arya et al., 2018). Hydroponics, which grows in environmentally controlled horticulture, is becoming a more popular technique for producing products around the world. Its numerous methods involve sustainability and growth efficiency by regulating climatic and system parameters (Zajkowski and Short, 2021). Hydroponics application of cooling systems to help lettuce receive the required temperature can provide conducive growing environment at its best. The Peltier cooling system is one of the alternative technologies that can be used to regulate the water temperature when growing lettuce in lowland areas of the Philippines.

This study aimed to develop and evaluate a modular hydroponics system with the use of a Peltier cooling system for romaine lettuce (*Lactuca sativa*) production. Particularly, this study aimed to (1) set-up and fabricate the modular hydroponics with Peltier cooling system; (2) evaluate the growth and yield performance of the lettuce grown in the Peltier-cooled modular hydroponics system; and (3) perform simple cost analysis.

Materials and Method

A. Conceptual Framework of the Study

The concept of the study (Fig. 1) shows the application of a Peltier cooling system in a modular hydroponics system wherein vertical and intensified farming technique was used to intensify the planting density of the romaine lettuce. This helped to increase production thus may result to increase rate of recovering capital cost. The water together with the nutrient solution was cooled using the Peltier cooling system, and was recirculated throughout the modular hydroponic system, which cooled the rootzone area of the lettuce and provided a prolific environment for lettuce production. This will provide needed data to analyze the objectives of the study

INPUT	PROCESS	OUTPUT
1. Materials used for modular hydroponics with Peltier cooling system for lettuce production.	1. Fabrication and Installation.	1. Fabricated modular hydroponics with the use of Peltier cooling system.
2. Thermometer, pH and EC pen type meter.	2. Water quality parameters, lettuce growth and yield monitoring.	2. Data gathered for the water parameters, growth and yield of lettuce.
3. Water with added nutrient solution.	3. Water monitoring.	3. Data for water and area productivity.
4. Production, operating cost, and area productivity and	4. Recording of the production and operating cost of the system, and computation of area productivity.	4. Simple cost analysis and area productivity.

Figure 1. Conceptual Framework of the study using Input-Process-Output Flow Diagram.

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B. Recirculating Hydroponics and Cooling System

The recirculating hydroponics system was composed of hydroponic channel, net cup, distribution pipe, drainage pipe, water reservoir, and the steel frame. The material used for the hydroponic channel was the tubular polyvinyl carbon (PVC) pipe having a dimension of 100 x 10 x 6 cm, each channel has a hole with a center-to-center distance with 20 cm each. The holes distance that was based on the planting distance of the romaine lettuce. The net cup was placed inside the hole which served as an anchorage for the lettuce to stay in place and with perforations that allows the lettuce to absorb the nutrients inside the hydroponic channel. The net cup used has a dimension of 5.1 cm height and 2.5 cm in diameter. The distribution pipe conveyed the water from the water tank into the hydroponic channel. It was made of ½ inch PVC pipe. The drainage pipe carried the water directly from the bottom of the hydroponic system returning it back to the water reservoir and it was also made of ½ inch PVC pipe. The nutrient solution container used was an ice chest available in the market with a dimension of 50 x 38 x 35 cm. Placed inside the ice chest was the Peltier cooling system.

The whole cooling system was enclosed in a plastic container with a dimensions of 43 x 30 x 24 cm. The cooling system consists of two pieces fans, heatsink, cold radiator, 2 pieces of Peltier module, and temperature setter that was attached to the side of the container. A heatsink and a fan were attached to the hot side of the Peltier module to remove the excess heat. The cold part of the Peltier was attached to a radiator which allows the water to cool down up to the set temperature. The cooling system was connected to a 12V power supply that is powered by electricity. The overall capacity of the fabricated Peltier cooling system is 0.012 cubic meter The capacity of the ice chest was 70 liters and the capacity of the cooling system inside was 12 liters. With the use of the temperature setter, the temperature was set to 20ºC to meet the needed rootzone temperature of lettuce. The Peltier module control was set to automatically turned-on when the temperature reaches 22ºC and it automatically turned-off when the temperature becomes 20ºC. A digital thermometer was used to double check that it reached the set temperature. The submersible water pump installed in the system assisted the nutrient solution circulation. It pushed the nutrient solution upward into the distribution pipe until it reached the top of the hydroponic system and then the water directly flows down to the drainage pipe by gravity force until it reached the water reservoir.

C. Experimental Design and Statistics

The design of the modular hydroponics system set-up was replicated. Two treatments were used for the study, the recirculating hydroponics system without cooling system and with cooling system, as Treatment 1 and 2, respectively. The data that was gathered and analyzed using the data analysis tool. The t-Test was used to evaluate if there was a significant difference between the two treatments that was used for the study.

D. Lettuce Production, Data Gathering and Monitoring

The romaine lettuce seeds were grown in seedling foam and were watered using sprinkler daily until the seeds germinated and ready to be transferred to the system. After 14 days from sowing and when three to four leaves emerged in all seedlings, the seedling foam was transferred carefully to the net cup and was transplanted into the hydroponics system. The hydroponic system set-up was grown for 30days inside a 300 x 300 x 220 cm greenhouse with an insect net.

The cooling system undergone calibration, pre-tested and recirculated for 24 hours before transferring the seedling on it. This is to ensure that the nutrient solution and the system was stable. The water temperature, pH and electrical conductivity (EC) were also tested before transferring the seedlings to the system. A simple water management was practiced during the conduct of the study. When the water level on the tank drops to 4 liters, additional water with nutrient solution will be added. The water parameters were checked every time that there was an addition of water to check the water quality by manual dosing. The quality of water inside the water reservoir was checked before starting to operate the Peltier cooling system, and it was done to maintain the good quality of water. The water quality parameters were checked using the pH-meter, EC-meter, and thermometer.

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In terms of the water quality, the water parameters were checked three times daily every 8:00 a.m., 2:00 p.m., and 6:00 p.m. The temperature of the water that was set on the Peltier cooler was 20ºC, while the pH was maintained between 6.0-7.0, and the EC was 1.2-1.8 mS/cm.

The plant growth parameters were measured every three days from transplanting until harvesting. This includes the length, width, and height. The lettuce was marked as sample and were measured on the longest and widest part of the leaf, and for the height from the bottom part to the top of the lettuce. The lettuce was harvested after 30 days and each was measured using a digital weighing scale.

Results and Discussions

A. Objective 1 – Modular Hydroponics System Design and Fabrication

The fabricated design of the modular hydroponic system applied with recirculating nutrient solution cooling system was used in rearing the romaine lettuce for 30days. The modular hydroponic system with peltier nutrient solution cooling system shown in Figure 2, were tested and calibrated for seven days to ensure that it is working properly. During the pre-testing, the highest ambient temperature taken was 35ºC and the lowest was 26ºC. In terms of the relative humidity (RH), the highest was 67%, and the lowest was 53%. The recorded water parameters showed that the highest temperature taken at Treatment 1 was 32ºC, while the lowest was 23ºC. For Treatment 2, the highest temperature taken was 25ºC and the lowest was 19ºC. In terms of pH level, Treatment 1 and Treatment 2 had an average pH level of 6, while in terms of EC of water, Treatment 1 has an average EC of 1.3 mS/cm and Treatment 2 had an average EC of 1.2 mS/cm.

The ambient temperature recorded the temperature comparison inside and outside the greenhouse at 8:00 a.m., 2:00 p.m., and 6:00 p.m. The average ambient temperature at 8:00 a.m. was 33.66ºC, 38.96ºC, at 2;00p.m., and 30.12ºC at 6:00 p.m. Ambient temperature influences the speed at which the plants process the energy, and changes in temperature had a direct effect on the process of photosynthesis, which will influence the growth and development of plants (Chia and Lim, 2022). The RH inside and outside of the greenhouse, taken every 8:00 a.m., 2:00 p.m., and 6:00 p.m. Observation showed that the average RH at 8:00 a.m. was 55%, while at 2:00 p.m. the average was 39%, and at 6 p.m. the average RH was 62%. The RH affects the leaf transpiration rate and can influence the water balance in the crop. An RH that is below the optimum level increases the resistance of the stomata, which leads to a reduction in carbon dioxide uptake as well as the photosynthesis rate (Chia and Lim, 2022).

Figure 2. The modular hydroponics and the peltier cooling system

The nutrient solution temperature was monitored and recorded and found that the average temperature for Treatment 1 was 27.2ºC, while at 2:00 p.m. it was 35.1ºC, and 30.4ºC at 6:00 pm. For the average temperature of Treatment 2, it was 20.8 ºC , 29.4ºC, and 26.8ºC, respectively. The nutrient solution tank temperature and the yield performance of the lettuce showed that providing a cooling system affected the production of lettuce. One of the important hydroponic characteristics was the necessity and ability to control the temperature of the nutrient solution. Growth and development can be affected when the

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temperature is above or below the optimum level. Having high temperatures in the root zone will result in reduced leaf, stem, and fresh and dry weight (Thakulla et al., 2021).

The daily pH taken on the water tank for both treatments for Treatment 1, the average pH at 8:00 a.m. and 2:00 p.m. was 6.46, while at 6:00 p.m. it was 6.49; while in Treatment 2, the average pH level was 6.29, 6.35, and 6.36, respectively. The pH recorded data showed that Treatment 1 had a higher pH level with an average of 6.47 level compared to Treatment 2, which has a pH level of 6.33. The behavior of pH was affected by the daytime temperature, and lower temperatures had a more stable pH compared to higher temperatures (Sulit, 2019).

The daily average EC of the nutrient solution for Treatment 1, was 1.4 mS//cm and 1.5 mS/cm for Treatment 2. High electrical conductivity decreases the possibility of water absorption by the plant as well as photosynthesis (Cometti et al., 2013). High fertilization can result in marginal leaf burn (Henry et al., 2018). The recommended range of EC was between 1.2 and 1.8 mS/cm was attained throughout the duration of the study.

B. Objective 2 – Growth and Yield Performance of Lettuce

The growth parameters, such as plant height, leaf length, and width, were measured and recorded. . Figure 3 presented that Treatment 1 and Treatment 2 have a significant difference in terms of leaf length, width and length, showing that the application of rootzone cooling for modular hydroponics helps the romaine lettuce leaf, as Treatment 2, to have better growth compared to the Treatment 1 that does not have a cooling system.

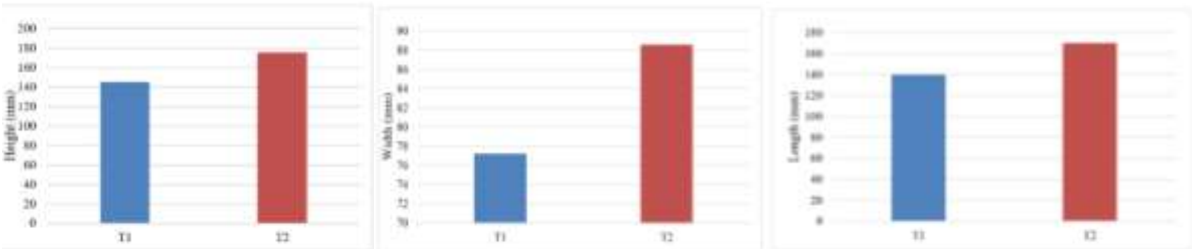

Figure 3. Average plant height, width and length of romaine lettuce

In terms of the yield of the lettuce, the result of the paired samples t-test calculation as showed in Table 1. Since the calculated p-value is approximately 0.0139 which is less than the standard significance level of 0.05, the result is statistically significant. This means that there is a statistically significant different in weight between Treatment 1 and Treatment, with Treatment 2 having a significantly higher mean weight of 54.8 grams compared to Treatment 1 (46.8 grams). T-test performed was shown in Table 4, and it showed that the two treatments had a significant difference in terms of their yield performance, and the treatment with rootzone cooling can produce a higher yield compared to the conventional hydroponics. Further checking of the results using traditional t-distribution table to find the critical value using the degrees of freedom and significance level at 0.05, two-tailed, gave a critical value (t_{crit}) of ±2.064. Since the calculated absolute t-statistic (|2.654|) is greater than the critical value (2.064), this confirms the finding of a significant difference.

Table 1. Paired samples T-test results of yield performance of lettuce

Group	N	Mean	SD	t	df	p-value
Treatment 1	25	46.8	9.92	2.654	24	0.0139*
Treatment 2	25	54.8	9.90			

*significant at 5%level

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Results of the experimental study shows significant effect of the provision of temperature control on lettuce production under lowland tropical condition with limited time of operation as well as limited temperature window and control. A similar study by Niam and Suhardiyanto in 2019 proved that treatment with rootzone cooling on leafy vegetables has higher yields than the treatment without rootzone cooling, the study revealed that 25ºC has 37.7% higher yields and 30ºC has 61.4% higher yields compared to the treatment that has no rootzone cooling.

C. Objective 3 – Cost Analysis

The cost analysis of the two treatments in terms of benefit-to-cost ratio and return on investments was summarized in Table 2. The investment cost includes the operational cost and the fixed capital investment (FCI). The operational cost was computed at ₱6469.19 which includes the seed cost, electricity, nutrient solution, and water cost projected for one year lettuce production. The material cost was divided based on the life span of the materials used, and the lowest life span was five years, and the total FCI was ₱4040.00, which resulted to a total investment cost of ₱10,509.19. The fixed cost was computed as the sum of the average interest on investment (AIOI) and the depreciation cost. The AIOI was ₱427.91, while the depreciation cost was ₱1891.65, and with that the total fixed cost was ₱2319.57. The total cost was ₱12,828.76 which was computed by adding the investment cost and fixed cost.

The gross income after 1 year was attained after multiplying the total yield (kg) by the market price of romaine lettuce and computed with 10 cycles every year for planting intensity; that includes the one (1) week fallow period in between the production for sterilization purposes of the system. The amount computed for the gross income was ₱7460.83. The net income was computed with the used of the gross income subtracted by the FCI, and the computed net income was ₱3420.83.

Table 2. Benefit-to-cost ration and return on investments of the lettuce production

	T2	T1
Present value of benefits	₱7460.825	₱6,172.63
Present value of cost	₱4,040.00	₱4,794.80
Benefit-cost ratio	**1.846738861**	**1.626600875**
Average net income	₱4,420.83	₱3,377.83
Fixed capital investment	₱4040	3794.8
Return of Investment	**85%**	**63%**

The present value of the benefit was the gross income, which is ₱7460.83, and the present value of the cost was the computed FCI, which was ₱4040.00 and with that, the computed BCR was 1.85. The BCR should be equal or greater than 1, therefore the study was beneficial. The ROI was obtained with the use of the average net income and the FCI, and with that the ROI of the study was 85%. The comparison of cost analysis was shown also in the table and it showed that despite having a lesser cost of Treatment 1, Treatment 2 still has higher BCR and ROI.

Conclusion and Recommendations

Based on the findings, the results demonstrates that the modular hydroponics system with the application of Peltier device as rootzone cooling system, Treatment 2, offers significant advantages over the conventional uncooled system, Treatment 1, for romaine lettuce production. The statistical analysis confirmed a significant difference, where Treatment 2 presented a higher growth performance and total yield. The system based on the presented analysis demonstrated an economically viable alternative of crop production as based on the benefit-to-cost ratio. The return on investment validated the financial justification for the initial cost of the system with a short payback period of one year and eight months. This constitute to the possibility of integration of Peltier cooling device successfully in mitigating rootzone temperature stress, leading to a substantial improvement in both farm productivity and economic feasibility of romaine lettuce cultivation in modular hydroponics.

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This study suggests to add sensory evaluation of the harvested romaine lettuce for better comparison in terms of the taste and quality of the produce. Further analysis on the effects of rootzone cooling on the physico-chemical characteristics of the lettuce leaves as well as the evapotranspiration process may also be investigated. The capacity of the modular hydroponic system can also be further intensify the production and to try other high valued crops for possible crop rotation.

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