CLSU International Journal of Science and Technology
www.clsu-ijst.org
ISSN 2507 -9638 (online)
The CLSU International Journal of Science and Technology was previously published as CLSU Scientific Journal since 1965.

Relationships of Water Quality Parameters for Hydroponic Production of Kale *(Brassica oleracea)* with In-Ground Passive Cooling System

Charlotte Joy Aprisun P. Catigday, Vitaliana U. Malamug, Christopher S. Pascual and Chito F. Sace

Department of Agricultural and Biosystems Engineering, College of Engineering, Central Luzon State University, Science City of Muñoz, Nueva Ecija, Philippines

Email for correspondence: catigdaycharlotte@gmail.com
Submitted: January 9, 2023. Accepted: June 15, 2023. Published Online: August 31, 2023

Abstract

Greenhouses in the Philippines face challenges related to high ambient air temperatures, affecting plant growth and yield. Additionally, water quality significantly influences plant development and yield in hydroponic systems. This study proposes a novel approach centered on cooling the nutrient solution to effectively regulate plant growth and yield with minimal investment and simplified management. A key component of this hydroponic system involves monitoring water quality, focusing on parameters like pH, EC (Electrical Conductivity), TDS (Total Dissolved Solids), and temperature. The research was conducted at the CLSU Hydroponics and Aquaponics Technology (CHAT) Demo Farm and Experiment Station, CLSU, Science City of Muñoz, Nueva Ecija, with the aim of developing a monitoring system for environmental and water quality parameters in an in-ground passive cooling system for hydroponic kale production. Comparative analysis between the in-ground passive cooling system (IGPCS) and a control (without cooling system) showcased the IGPCS's capacity to effectively reduce nutrient solution temperature by up to 3°C. This reduction led to increased kale yield and lowered water consumption. Notably, the study revealed an intricate interrelationship among water quality parameters, illustrating their critical role in hydroponic systems. These findings offer valuable insights into optimizing hydroponic setups in tropical climates, promoting sustainable agriculture by enhancing productivity and water efficiency through innovative cooling solutions.

Keywords: in-ground passive cooling; water quality; hydroponics; kale; water productivity

Introduction

Hydroponic systems represent an innovative approach to agriculture, granting precise control over nutrient distribution among plants (Calpas, 2001). This technology is particularly valuable for local vegetable and fruit production, addressing the inadequacy of traditional systems to meet local supply demands in the Philippines (Holmer, 2010). Among the various crops, kale has gained prominence due to its versatility and high nutritional value. However, optimal hydroponic cultivation of kale in tropical climates is hindered by rising greenhouse temperatures, a crucial factor impacting plant growth and development (Levitt, 1980).

The hydroponics system relies on the nutrient solution as its central component for sustaining plant growth (Anderson et al., 1989).

DOI: https://doi.org/10.22137/ijst.2023.v7n2.07

Maintaining this solution at an ideal temperature is vital, enhancing oxygen levels and overall crop performance in tropical settings (Pure Hydroponics, 2015). Lowering the nutrient solution temperature also leads to increased water absorption and higher hydroponic crop productivity (Commetti et al., 2013).

Addressing the greenhouse temperature challenge necessitates effective cooling solutions. Conventional methods involving chillers and mechanical devices prove costly and environmentally unfriendly (Li & Wang, 2015). In contrast, the in-ground passive cooling system offers a natural and cost-effective alternative, utilizing the ground's lower temperature to dissipate heat from the nutrient solution (Samuel et al., 2013). Effective control of nutrient solution temperature is paramount for hydroponically grown plants, surpassing the importance of regulating air temperature (Xu & Huang, 2000). On the other hand, in hydroponic kale cultivation, maintaining the right pH (5.5-6.5), EC, and TDS levels is crucial. Proper pH ensures nutrient availability, while EC and TDS control nutrient strength for optimal growth and quality.

Objectives

The general objective of the study is to develop a monitoring system of water quality parameters of in-ground passive cooling system for hydroponic production of kale. Specifically, the study aimed to:

1. determine the relationships of water quality parameters such as pH, EC, TDS, and temperature for kale production;

2. compare the performance of an IGPCS and control of hydroponically grown kale; and

3. evaluate the water productivity of the IGPCS.

Materials and Methods

The conceptualization of the study was based on the principle of cooling the nutrient solution to effectively regulate plant growth and yield, even when exposed to high air temperatures (He, et al., 2009). An essential aspect of a functional hydroponics system is monitoring water quality; thus, this study utilized a monitoring system to track water quality and environmental parameters.

The nutrient solution underwent monitoring to maintain optimal nutrient levels, ensuring they were neither too low to inhibit growth nor too high to pose potential toxicity risks. Tropical greenhouses in our country face challenges related to ambient air temperature. Consequently, this study directly addressed this issue by lowering the nutrient solution's temperature using the in-ground passive cooling system.

This study utilized both the IGPCS and a control to compare performance based on kale growth and yield, considering parameters such as leaf length, leaf width, number of leaves, and weight. Additionally, the study assessed water productivity associated with utilizing IGPCS.

Environmental factors affecting kale production, such as temperature and relative humidity, were closely monitored using temperature and relative humidity sensors both inside and outside the greenhouse. Likewise, water quality parameters including pH, EC, TDS, and temperature were meticulously monitored through the integrated monitoring system. Furthermore, relationships among these water quality parameters were established.

Time and Place of the Study

The study was conducted on February 2020 to March 2020 at the CLSU Hydroponics and Aquaponics Technology (CHAT) Demo Farm and Experiment Station, of the Academic Research Council, Central Luzon State University (CLSU), Science City of Muñoz, Nueva Ecija. The geographical coordinates are approximately 15.7390835 latitude and 120.9433786 longitude, experiencing a temperature range of 19°C to 40°C.

Preparation of Greenhouse

The existing greenhouse design was enhanced by replacing the 60% black shade net and adding insect nets for sun and pest protection. The system was disinfected by flushing water through growing pipes to clear any residual media. Growing pipes and nutrient solution reservoirs were inspected and cleaned, ensuring a healthy crop environment. Solarization for a week helped prevent pests and diseases before transplanting kale seedlings.

Monitoring System for Water Quality Parameters

The monitoring system was established to oversee water quality parameters using devices like an analog electrical conductivity sensor, DS18B20 waterproof temperature sensors, and Analog pH meter v2.0. These instruments were installed in the nutrient solution reservoirs of both systems (with IGPCS and control) and connected to a data logger.

Each data log played a pivotal role in ensuring that water quality parameters were kept at optimal levels required for the growth and development of kale. This monitoring system was an integral component of the study, facilitating close observation of parameter variations in response to daily fluctuations in time and temperature within the kale's environment.

To achieve the optimal temperature range of 20-30°C for the crops, the surface where the 4-inch PVC pipe loops were placed needed frequent moistening due to intense heat. pH levels were maintained within the range of 5.8–6.8, a range conducive to the growth of most plants (Sace, 2008). Adjustments were made to the nutrient solution by adding weak acid to decrease pH and baking soda to increase it. Furthermore, the EC was maintained within the range of 1.5–2.8 mS/cm (Samarakoon et al., 2006).

Monitoring System for Environmental Parameters

Regular monitoring of environmental parameters (temperature and relative humidity) was conducted 24 hours a day with 15-minute interval using DHT22 temperature and relative humidity sensors, both inside and outside the greenhouse. The data obtained were directly recorded into the data logger.

Experimental Design and Field Layout

The study employed two-factorial Completely Randomized Design (CRD) with the cooling method as the main factor and the locations of growing pipes as a sub-factor, as illustrated in Figures 1 and 2.

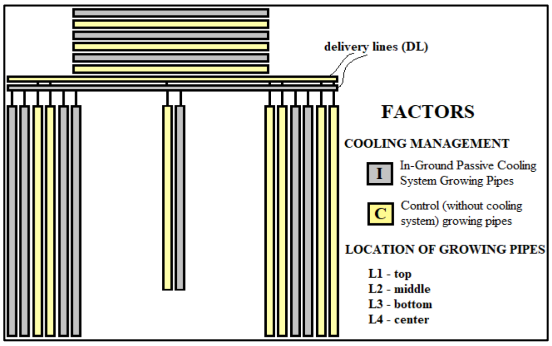

Figure 1. Experimental layout (top view of growing pipes)

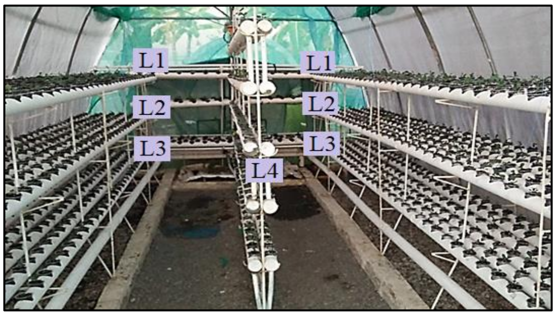

Figure 2. Growing pipes' location at NFT setup

Nutrient Solution Management

This study utilized the nutrient solution formulated by the CLSU Hydroponics and Aquaponics Technology (CHAT) Demo Farm and Experiment Station. The dosing of the nutrient was conducted manually every day between 6:00 AM and 8:00 AM when the nutrient solution temperature was stable for both the IGPCS and the control. The dosage of the nutrient solution was adjusted by increasing it through the addition of nutrient solutions A and B, and decreased by adding water to the nutrient solution reservoir. Nutrient solutions with and without the cooling system were managed through careful monitoring using the installed water quality parameters monitoring system, and adjustments were made manually to achieve the optimum level required by the kale plant.

Cultural Practices

Kale seeds were sown in the seedbox with pumice and began to germinate after 1-2 days. After 10 days of planting the seeds, the kale seedlings were transferred into foam and exposed to the sun for three days for acclimatization. Following acclimatization, the kale seedlings with foam were transplanted into plastic cups with the media and placed into the holes of the growing pipes. Each cup was perforated at the bottom and sides for capillary action and proper drainage. Furthermore, a

DOI: https://doi.org/10.22137/ijst.2023.v7n2.07

mixture of foam, carbonized rice hull, and pumice was utilized as growing media to support the roots of the kale.

System Operation

Two 69-watt water pumps were used to circulate the nutrient solution from both the nutrient solution reservoir and the underground pipe to the growing pipes. Each nutrient solution reservoir was equipped with a separate water pump to prevent the mixing of nutrient solutions from different cooling methods, as this was a subject of investigation. Both water pumps operated continuously with a 15-minute interval for auto shut on-off, managed by an automatic timer to prevent potential overheating. The cooled nutrient solution was distributed to the crops in the growing pipes, and the nutrient solution returned to the reservoir through gravity, similar to the nutrient solution in the control setup.

Harvesting

Kale samples were harvested after 31 days of propagation. Each kale plant, including its roots, was harvested and promptly weighed using a digital weighing balance. The number of leaves was determined by counting the leaves at harvest and categorizing them as marketable for the sample plants. Additionally, the length and width of fully expanded leaves from the sample plants were measured using a foot rule.

Water Productivity

Water productivity is defined as crop yield per liter of water consumed. The water productivity of with and without cooling system was computed separately and was compared. It was computed using this formula:

$W_p = Y_a/W_c$

where: W_p – water productivity, g/L

Y_a – average yield, g

W_c – water consumption, L

Data Analysis

The collected data on environmental and water quality parameters were analyzed using trend analysis in Microsoft Excel. Analysis of variance (ANOVA) was conducted using R Studio software version 3.3.0 from the Statistical Tool for Agricultural Research (STAR) in a Completely Randomized Design (CRD). Mean comparisons were carried out using the Least Significant Difference (LSD) Test at the 5% level.

Results and Discussion

Environmental Parameters

Temperature

Temperature plays a vital role in crop productivity and is the primary environmental factor affecting the quality and growth of plants (Hatfield & Prueger, 2015). The weekly average air temperatures inside and outside the greenhouse during the study are shown in Figure 3. The air temperature within the greenhouse exhibited a more stable trend with an average deviation of 4.67, in contrast to the outside temperature, which had an average deviation of 5.83, indicating greater variability. Additionally, the outside air temperature from 10:00 am to 2:00 pm was higher than inside due to the greenhouse's shade net, which helps in reducing the temperature indoors.

The optimum temperature range for kale growth is between 20-30 °C (Lefsrud et al., 2005). The temperature inside the greenhouse exceeded this desired range between 8:00 am and 5:00 pm. However, given that the Tuscan variety of kale is a summer crop, the high air temperature, specifically reaching 36 °C inside the greenhouse, did not negatively impact the growth and development of kale. Therefore, this higher temperature is still acceptable for kale production within the greenhouse (Lefsrud et al., 2005).

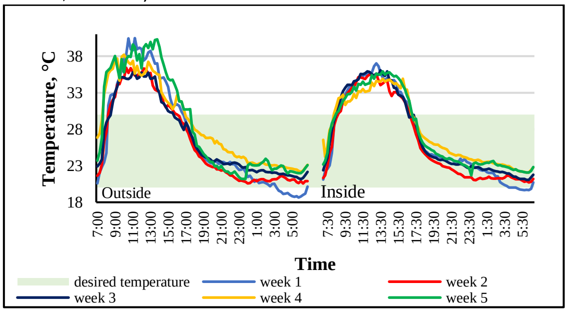

Figure 3. Weekly average air temperature outside and inside the greenhouse with 20-30 °C optimum range

Relative Humidity (RH)

The RH levels directly affect the physiological growth of the crops, influencing the rate of absorption of the nutrient solution and the amount of evapotranspiration (TNAU, 2020). Figure 4 shows the weekly averaged relative humidity both inside and outside, with a 50-70% desired RH range that is favorable for most plant growth inside the greenhouse (Brechner & Both, 2012). Most of the RH readings inside the greenhouse range from 50-70% between 7:00 am to 5:00 pm, which is desirable for the plants. The RH was higher than the optimum range between 5:00 pm to 6:00 am when the temperature was low during this time.

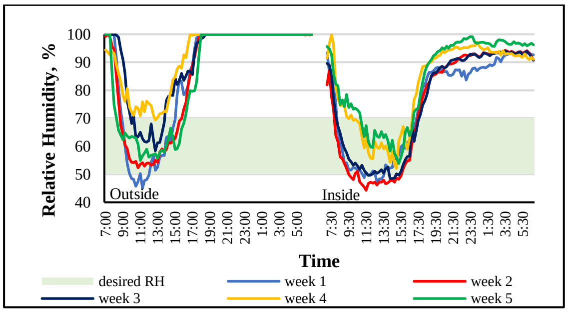

Figure 4. Weekly average relative humidity outside and inside the greenhouse with 50-70% optimum range

Water Quality Parameters

Nutrient Solution Temperature

The temperature of the nutrient solution influences the crop's uptake of water and nutrients. Thus, temperature monitoring using the monitoring system was conducted. The weekly average temperature of the nutrient solution collected in IGPCS and control is shown in Figure 5, with the optimum temperature range of 18–28°C as listed by (Nxawe et al., 2009).

The weekly temperature of the nutrient solution with IGPCS was generally lower than the temperature of the control by about 3°C. The temperature trend with IGPCS was more consistent compared to the control. The temperature of water in the reservoir buried in the ground at a depth of 1-8 meters remained almost constant and was not easily affected by ambient temperature (Popiel et al., 2001). However, the temperature of water in the reservoir with a shallow depth of below 1 meter is very sensitive to short-term changes in weather conditions. Generally, the temperature of the nutrient solution was within the acceptable range for growing kale in a hydroponic system, even when it was 3°C higher than the optimum temperature. An increase or decrease of about 6°C in the optimum temperature has no significant influence on water and nutrient uptake by crops (Trejo et al., 2007).

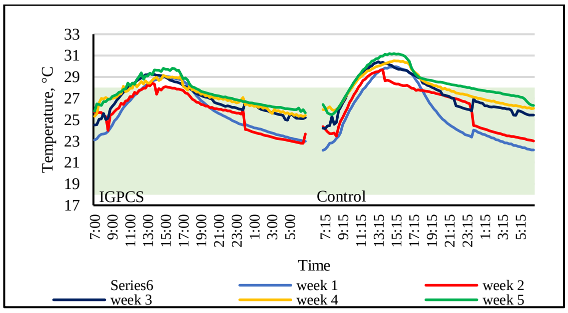

Figure 5. Weekly average temperature of with IGPCS and Control with 18-28 °C optimum range

Electrical Conductivity (EC)

The total amount of salts in a solution is referred to as Electrical Conductivity (EC). The range of EC to be maintained for various crops in a hydroponic system is about 1.5 to 2.8 mS/cm (Samarakoon et al., 2006). The weekly changes in EC of the nutrient solution are depicted in Figure 6, where it can be observed that it started with a low EC until an increase in EC value was noted after the first week for both with IGPCS and control. As stated by Ledtester (2010), seedlings require a low EC to avoid fertilizer burn from over-feeding. As the plant matures, the food concentration can be increased to provide more nutrients to the plants through the water. The EC value of with IGPCS and control changes from time to time due to various factors affecting the EC of the nutrient solution. The average of weekly EC readings for the control was more scattered than with IGPCS, since temperature is one of the factors affecting the EC of the nutrient solution. Additionally, it shows that the EC reading of systems with IGPCS and control was almost within the ideal EC range.

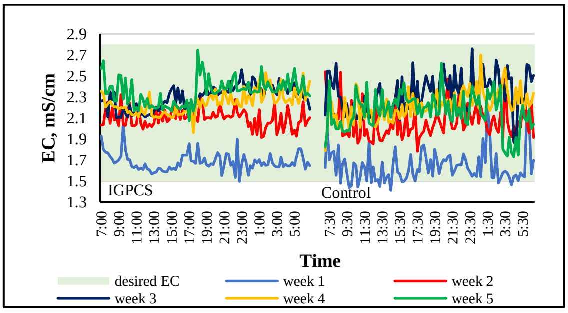

Figure 6. Weekly EC average of with IGPCS and Control with 1.5-2.8 optimum range

Total Dissolved Solids (TDS)

Total dissolved solids refer to the measurement of salts, anions, cations, and metals in the nutrient solution. It is measured in parts per million (ppm) and is directly proportional to EC. If the EC value increases, the TDS value will also increase, as shown in Figure 7.

The TDS readings were obtained using the same sensors as EC. Therefore, the TDS values within the study were within the ideal TDS range, which was consistent with the EC results. Based on extrapolation, the ideal TDS range was determined to be 950-1800 ppm. The TDS and EC readings changed from time to time for both with IGPCS and control, with more fluctuations observed in the control.

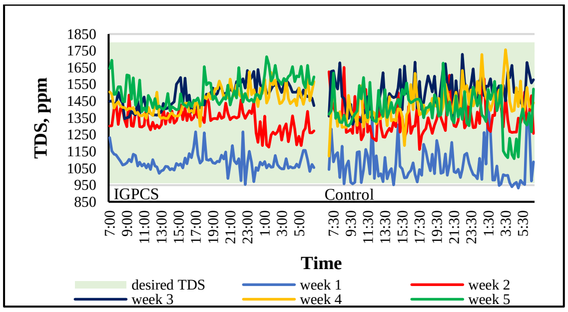

Figure 7. Weekly TDS average of with IGPCS and control with 950-1800 ppm optimum range

Potential Hydrogen (pH)

The pH measures the acidity or alkalinity of the nutrient solution within an acceptable range of 5.8-6.8, where plant roots absorb essential nutrients needed for the plants' normal growth (Sace, 2008). Based on Figure 8, the weekly average pH readings of with IGPCS and control were almost all within the range acceptable for the crops' growth and development.

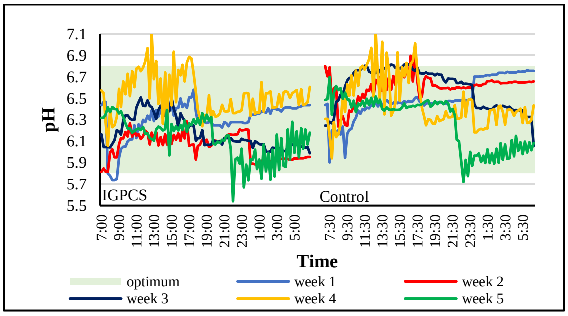

Figure 8. Weekly average pH of with IGPCS and control with optimum range of 5.8-6.8

Relationships of Water Quality Parameters

Potential Hydrogen vs. Nutrient Solution Temperature

The relationship between the temperature and pH of the nutrient solution is important to note because the pH value of a solution is directly dependent on the temperature, and a pH value without a corresponding temperature value is incoherent (Westlabblogcanada, 2017). Plants constantly absorb nutrients from the solution, causing the pH to change over time (Andrew, 2019). Various variables such as evaporation, the amount of light, and temperature can affect pH levels in an aqueous solution (Ledtester, 2010).

Figure 9 illustrates the relationship between pH and temperature of the nutrient solution for both IGPCS and control. Both systems show a trend where the temperature of the nutrient solution almost directly affects the pH. The pH increases with the rising temperature of the nutrient solution and slightly decreases with decreasing temperature. A temperature above 20 °C improves phosphate uptake, resulting in an increase in the pH of the culture solution; however, a decrease in temperature reduces phosphate uptake and, consequently, lowers the pH (Kim et al., 2005). In low light conditions where the temperature is low, plants absorb more potassium and phosphorus from the nutrient solution, causing increased acidity (pH drops). Conversely, in intense light with high temperature, plants absorb more nitrogen, leading to decreased acidity (pH rises) (Ledtester, 2010). Therefore, the established relationship between pH and temperature of the nutrient solution from IGPCS and control was directly proportional to each other.

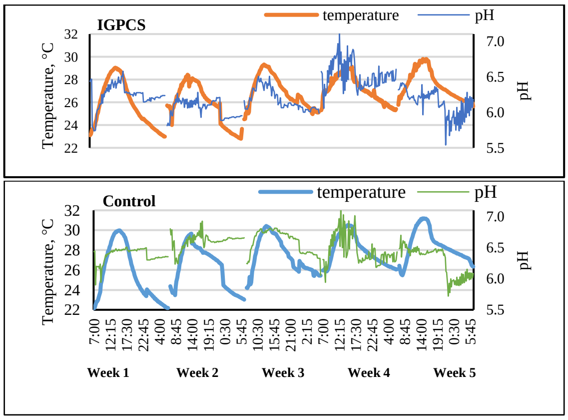

Figure 9. Relationship of pH and temperature of nutrient solution at IGPCS and control

Electrical Conductivity vs. Nutrient Solution Temperature

High temperatures and high light intensity during the summer season tend to induce unbalanced water uptake and mineral elements in hydroponically cultured crops (Kim et al., 2005). Thus, establishing the relationship between temperature and EC of the nutrient solution is important. As shown in Figure 10, from the third week to the last week, there are slightly clear trends indicating that EC decreased with an increase in the temperature of the nutrient solution and increased with a decrease in temperature. Water uptake by the plants increases with rising temperature, causing the solution to weaken as plants utilize nutrients (Adam, 1980). Since the temperature of the nutrient solution was still acceptable for kale production, the findings of this study demonstrated that an increasing temperature weakens the concentration of the nutrient solution as plants uptake more water and nutrients. On the other hand, fewer nutrients were absorbed by the plants at lower temperatures. Therefore, the established relationship between EC and temperature of the nutrient solution was inversely proportional to each other.

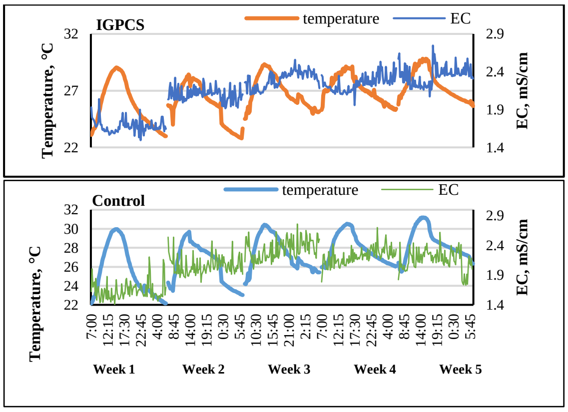

Figure 10. Relationships of nutrient solution temperature and EC at IGPCS and Control

Total Dissolve Solids vs. Nutrient Solution Temperature

Figure 11 shows the TDS versus temperature of nutrient solution from IGPCS and control, which have the same result with EC.

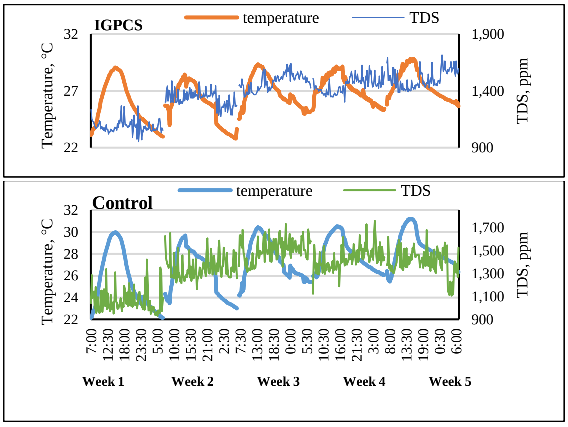

Figure 11. Relationships of nutrient solution temperature and TDS of IGPCS and Control

Electrical Conductivity vs Total Dissolve Solids

TDS provides an accurate measurement of the amount of solids dissolved in a water sample, while EC offers a clear indication of the concentration of salts in a water sample. In a hydroponic nutrient solution, the EC and TDS values exhibit a more direct correlation due to the high percentage of dissolved salts (Max, 2019). Figure 12 depicts a clear relationship between TDS and EC, which is directly proportional to each other. If the EC value increases, the TDS value will increase, and vice versa. Therefore, the established relationship between EC and TDS of the nutrient solution, both IGPCS and control, was directly proportional to each other.

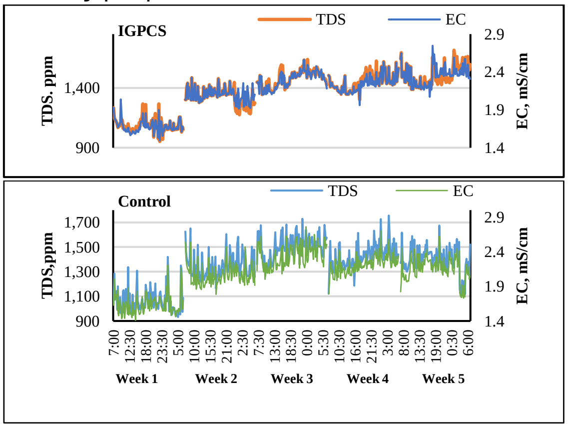

Figure 12. Relationships of TDS and EC at IGPCS and Control

Potential Hydrogen vs Electrical Conductivity

Establishing the relationship between pH and EC is important because the pH is likely to rise over time as the plants absorb nutrients. Based on Figure 13, there is no clear trend in the relationship between pH and EC. At certain points, when the EC value increases, the pH value decreases, and vice versa. Every nutrient is absorbed by plants at a greater or lesser rate depending on the pH of the nutrient solution; hence, pH rises as plants continuously absorb nutrients from the solution (Andrew, 2019). Based on the findings from other relationships, it can be observed that the nutrient solution weakens as plants take up nutrients. Therefore, it can be noted that nutrient uptake by plants increases with an increase in pH value, resulting in a decrease in EC value due to the increased uptake of nutrients by the plants. Additionally, the results of the established relationships of different water quality parameters mentioned above can shed light on the relationship between pH and EC, where pH increases with decreasing EC. Consequently, the established relationship between TDS and pH from the nutrient solution, both IGPCS and control, was found to be inversely proportional.

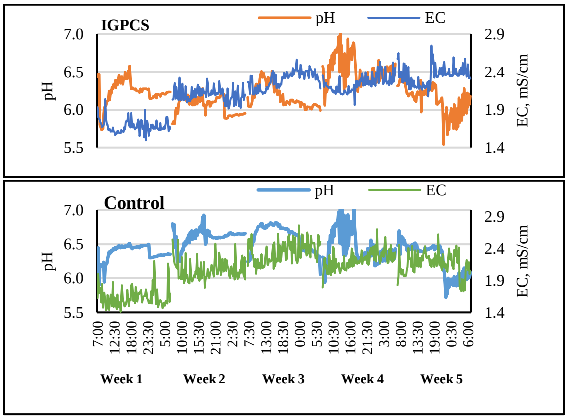

Figure 13. Relationships of pH and EC at IGPCS and Control

Agronomic Parameters

All agronomic parameters, such as leaf length, leaf width, and the number of leaves of kale collected at harvest, showed no significant difference concerning cooling management. However, they exhibited significant differences based on the locations of the growing pipes. Therefore, kale can grow effectively with or without the cooling system, provided there is proper monitoring of the nutrient solution. However, the location of the growing pipes directly affects the growth and development of the crops. Plants located at the top and center growing pipes tend to grow better than those at growing pipes that receive less sunlight. As observed, plants grown at the bottom growing pipes of control exhibited a significant retardation in growth and development.

Total Yield

The weight of kale, including the roots, was measured for the whole plant at harvest from sample plants per treatment. The average weights of the samples are displayed in Figure 14. The control at the bottom position of the growing pipes exhibited the lightest weight compared to the other treatments. Conversely, the heaviest weight was observed in the plants planted at the top layer with IGPCS.

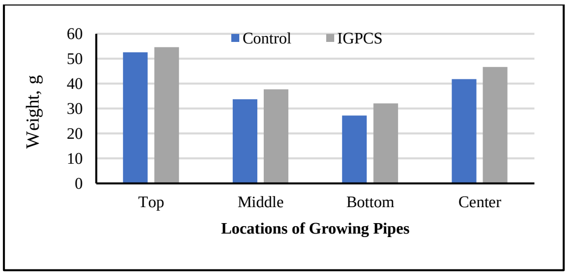

Figure 14. Average weight (g/plant) of kale at harvest affected by the location of growing pipes and cooling management

The statistical analysis presented in Table 1 indicates that plants grown in the control at the bottom location of the growing pipe had the least biomass, significantly lower than the plants grown elsewhere in the system. This result aligns with the findings of other agronomic parameters considered in this experiment. Additionally, cooling management showed comparability with each other but not in terms of location. Kale plants grown at the top growing pipes were significantly heavier than plants planted at different locations. However, plants grown at the middle and center locations were comparable in weight, as were plants grown at the middle and bottom locations of the growing pipes. The bottom and center locations of the pipes showed a significant difference in the weight of kale plants.

Table 6. Average weight (g/plant) measurement of kale at harvest grown in different locations of growing pipes and cooling management.

TREATMENT			MEAN
Growing Pipes	Cooling Method		
	IGPCS	Control	
Top	57.72	52.88	57.39[a]
Middle	39.92	36.20	38.06[bc]
Bottom	31.72	29.64	30.68[c]
Center	46.67	41.80	44.23[b]
MEAN	44.01	41.18	
GRAND MEAN			42.59

Water Consumption

Table 2 illustrates the water consumption of kale using IGPCS, which was 1.04 L per plant, and control, which was 1.17 L per plant. Therefore, the control exhibited higher water consumption compared to the with IGPCS, with a difference of approximately 0.13 L per plant. Consequently, water uptake by the plants increases with the rising temperature of the nutrient solution (Adam, 1980). A cold solution increased NO3− uptake and thin-white root production but reduced the overall water uptake of the plants (Calatayud et al., 2008).

Water Productivity

The water productivity when using IGPCS was 42.32 g/L, whereas in the control, it was 35.73 g/L, as depicted in Table 1. Consequently, the water productivity of kale production in the NFT hydroponics system was higher with IGPCS compared to the control. This difference can be attributed to the influence of nutrient solution temperature on the crop's uptake of water and nutrients (Calatayud et al., 2008).

Table 2. Water consumption of kale and water productivity of system with and without cooling

COOLING METHOD	IGPCS	CONTROL
Water Consumption (L)	1.04	1.17
Water Productivity (g/L)	42.32	35.73

Conclusion

Based on results of this study, the following conclusions are made:

1. Relationships among water quality parameters were established through trend analysis in Microsoft Excel. EC and TDS of the nutrient solution showed an inverse relationship with pH and temperature. Consequently, EC and TDS were directly proportional, as were pH and temperature. Regulating one water quality parameter affected others, highlighting the interconnectedness. Monitoring these parameters closely using the monitoring system was essential for understanding their relationships.

2. The performance of IGPCS and the control system were comparable in terms of kale growth and yield, including leaf length, leaf width, number of leaves, weight, and yield at harvest. However, the location of growing pipes significantly influenced the results, affecting the amount of sunlight received by the crops. IGPCS effectively reduced the nutrient solution's temperature by up to 3°C, resulting in higher yields compared to the control.

3. Water consumption per kale plant was 1.17 L in the control and 1.04 L in the IGPCS, indicating that IGPCS reduced water consumption while increasing productivity. The water productivity of IGPCS was 42.32 g/L, whereas it was 35.73 g/L in the control. Given these findings, utilizing IGPCS in tropical areas could significantly enhance kale production, achieving higher yields while conserving water.

Recommendations

Based on the findings of this study, the following are recommended,

1. Redesign the layout of growing pipes to ensure equal sunlight distribution to crops inside the greenhouse, aiming for a more balanced statistical layout.

2. Optimize the design of IGPCS to achieve the desired nutrient solution temperature. This could be done by increasing the depth of the system beyond 2 meters or extending the series of underground pipes.

3. Conduct further research to enhance nutrient solution efficacy by exploring the use of magnetized water.

Acknowledgements

First and foremost, praises and thanks to Almighty God for His guidance for without His grace this study will not become successful. The author would like to express her deepest gratitude to her advisory committee for helping her finalize her study. To her adviser, Dr. Chito F. Sace, for his patience, motivation, enthusiasm, guidance, and immense knowledge throughout the duration of the study. Also, to the members of the committee, Dr. Vitaliana U. Malamug and Engr. Christopher S. Pascual, for their encouragement, constructive criticism, insightful comments, and suggestions in improving this manuscript.

DOI: https://doi.org/10.22137/ijst.2023.v7n2.07

Her appreciation goes to her family who inspired her to do her best and supported her from the very beginning. She recognizes the invaluable assistance that they all provided to finish all her undertakings. She would like to extend her special thanks to the CLSU International Alumni Association, Inc. for choosing her as one of the scholars, especially to Engr. Joselito Viray and Engr. Norma Viray for their financial support for this study.

Her sincere thanks to CLSU Hydroponics and Aquaponics Technology (CHAT) for giving her the opportunity to successfully conduct this study. This study would not be successful without the help and effort given by Engr. Jude Ancheta and the staff of CHAT. Her deepest gratitude to all the people of the Department of Agricultural and Biosystems Engineering.

Finally, her appreciation to all her friends and to her BSABE 5-2 classmates and dorm mates at Ladies Dorm 4 for their never-ending support and encouragement.

References

Adam, P. (1980). Nutrient uptake by cucumbers from recirculating solutions. Acta Horticulturae, 98, 119-126.

Anderson, M., Bloom, L., Queen, C., Ruttenburg, M., Stroad., & Thomas, D. (1989). Understanding hydroponics. VITA Publication.

Andrew. (2019). Hydroponic nutrient solution (easy guide). Smart Garden Guide. Retrieved from https://smartgardenguide.com/hydroponic-nutrient-solution-easy-guide-2/?unapproved=3942&moderation-hash=0bf01c75674cef9a4551fed11b6ebede#comment-3942.

Brechner, M., & Both, A. (2012). Hydroponic lettuce handbook. Cornell University CEA Program. http://www.cornellcea.com.

Calatayud, A., Gorbe, E., Roca D., & Martínez P. F. (2008). Effect of two nutrient solution temperatures on nitrate uptake, nitrate reductase activity, NH4+ concentration and chlorophyll a fluorescence in rose plants. Environmental and Experimental Science.

Calpas, J. (2001). Management of the greenhouse environment. Government of Alberta, Agriculture, and Rural Development.

Commetti, N., Bremenkamp, D., Galon, K., Hell, L., & Zanotelli, M. (2013). Cooling and concentration of nutrient solution in hydroponic lettuce crop Horticulura Brasileira, 31(2).

Hatfield, J. L., Prueger, J. H. (2015). Temperature extremes: Effect on plant growth and development. Weather and Climate Extremes, 10(Part A), 4-10. https://doi.org/10.1016/j.wace.2015.08.001.

He, J., Tan, L., & Lee, S. (2009). Root-zone temperature effects on photosynthesis, 14C-photoassimilate partitioning and growth of temperate lettuce in tropics. Photosynthetica, 47, 95-103. https://doi.org/10.1007/s11099-099-0015-6.

Holmer, R. (2010). Community-Based Vegetable Production Systems: An Answer to the Food and Sanitation Crisis of Urban Poor in the Philippines? Acta horticulturae, 881, 125-130. https://doi.org/10.17660/ActaHortic.2010.881.12.

Kim, K. J., Cho, Y. S., Kwon, O. K., Cho, M. W., Hwang, J. B., Bae, S. D., & Jeon, W. T. (2005). Effect of pH and EC of hydroponic solution on the growth of greenhouse rose. Asian Journal of Plant Sciences, 4, 348-355.

Ledtester. (2010). pH and nutrient uptake charts!. Hollywood, California. Retrieved from https://www.420magazine.com/community/threads/ph-and-nutrient-uptake-charts.114733/.

Levitt, J. (1980). Chilling, freezing and high temperature stresses, responses of plants to environmental stress. Academic Press.

Lefsrud, M. G., Kopsell, D. A., Kopsell, D. E., & Curran-Celentano, J. (2005). Air Temperature Affects Biomass and Carotenoid Pigment Accumulation in Kale and Spinach Grown in a Controlled Environment. HortScience, 40, 2026-2030.

Li, H. G., & Wang, S. X. (2015). Technology and studies for greenhouse cooling. World Journal of Engineering and Technology, 3, 73-77.

Max. (2019). TDS, EC, and PPM explained. Green and Vibrant. Retrieved from https://www.greenandvibrant.com/tds-ec-ppm.

Nxawe, S., Laubscher, C., & Ndakidemi, P. (2009). Effect of regulated irrigation water temperature on hydroponics production of Spinach (Spinacia oleracea L.). African Journal of Agricultural Research, 4(12), 1442–1446.

Popiel, C., Wojtkowiak, J., & Biernacka, B. (2001). Measurements of temperature distribution in ground. Experimental Thermal and Fluid Science, 25, 301-309.

Pure Hydroponics. (2015). Enabling high-quality crops to be produced-even under the most challenging of conditions.

Samuel, D. L., Nagendra, S. S., & Maiya, M. (2013). Passive alternatives to mechanical air conditioning of building: A review. Build. Environ., 66, 54-64.