ADVANCES IN AGRICULTURAL AND FOOD RESEARCH JOURNAL

Short Communication

The Effect of The Fertilizer Water Cycle on The Water Quality of The Hydroponic System

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Abstract: Water quality changes in the hydroponic planting system planted with curly kale (kailan) were examined by measuring physiochemical analysis over three planting cycles. The water quality parameters measured included temperature, pH, Electrical Conductivity (EC), Biochemical Oxygen Demand (BOD), and Chemical Oxygen Demand (COD). In this study we also measured 13 elements in water samples which are Ammoniacal Nitrogen (AN), Phosphate (PO_4), Sulphate (SO_4), Nitrate (NO_3), Boron (B), Calcium (Ca), Copper (Cu), Iron (Fe), Potassium (K), Magnesium (Mg), Manganese (Mn), Phosphorus (P) and Zinc (Zn). The analysis results compare the observed values with those recommended by the National Water Quality Standards (NWQS) Class IV (water quality standard for irrigation purposes). Chemical analysis of AN, B, Cu, Mn, Zn, COD, and BOD obtained from water sampling cycles 1–3 remained within the acceptable range. The determination of minerals was also relatively low compared to the NWQS value. However, the water analysis results for cycle 3 showed that Nitrate and Fe levels exceeded the maximum limit set by NWQS. Phosphate and K demonstrated a similar pattern, even though no fixed value exists for these parameters in the NWQS. The results of the water quality analysis during the cultivation process demonstrate that the fertilizer water can still be recycled, contributing to water conservation and pollution control.

Keywords: water quality; curly kale; fertilizer; cycle; hydroponic

Received: 1st July 2024

Accepted: 1st February 2025

Available Online: 21st February 2025

Published: 30th June 2025

Citation: Saad, M. J., Hamim, N. M., Jaafar, J., *et al.* The effect of the fertilizer water cycle on the water quality of the hydroponic system. *Adv Agri Food Res J* 2025; 6(1): a0000578. https://doi.org/10.36877/aafrj.a0000578.

1. Introduction

Food security is essential to ensure a supply of nutritious food for the people of Malaysia. One primary source of natural nutrients is the vegetables grown on farms. As agricultural land diminishes due to the expansion of residential, industrial, and other areas, adopting new approaches for cultivating and producing vegetables becomes crucial. Hydroponics, an innovative soilless cultivation technique, has emerged as a viable solution to the challenges posed by conventional agriculture. In this method, plants are grown in nutrient-rich water solutions rather than traditional soil, allowing precise control over growing conditions and resource utilization (Szekely *et al.*, 2022). Hydroponics differs from conventional agriculture by providing a controlled environment, thus eliminating the uncertainties associated with soil-based cultivation (Ragaveena *et al.*, 2021). Nutrients are delivered directly to plants through nutrient solutions, ensuring efficient uptake and utilization (Verrone, 2021). Consequently, hydroponic Plant Houses for producing healthy vegetables have been established globally (Kozai, 2013).

Hydroponics, a method of growing plants without soil (Jones, 1982), effectively produces plants indoors. It is a suitable option for urban societies, helping to reduce food production energy costs (Gentry, 2019). The Plant House was designed to grow vegetables in a controlled environment using tiered hydroponic racks (Kozai, 2011). This system was developed to maximize yield in limited spaces, increasing the output per unit area (Hafeifi *et al.,* 2020). The Plant House includes multiple components, such as an overflow-type hydroponic system.

The pH value measures the acidity level of water (Davis & McCuen, 2005). High acidity in water can negatively impact plant growth, damage agricultural equipment, and reduce the effectiveness of fertilizers and pesticides. The optimal pH range for agricultural water is between 5.0 and 9.0. Salinity measures the dissolved salt content in water, including ions such as Na, Ca, Mg, Cl, and sulfate (Dobermann & Fairhurst, 2000). Salinity is measured by electrical conductivity (EC) in microsiemens per meter (µS/m). EC is determined by measuring the electrical resistance between two electrodes (Shainberg & Oster, 1978). Heavy metals are harmful pollutants that are toxic to the environment. The most common heavy metal contaminants include arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), lead (Pb), and zinc (Zn). However, plants require small amounts of Cu, Zn, Mn, and Fe as micronutrients. High concentrations of heavy metals can poison plants. These metals are absorbed through plant roots and accumulate in plants and the human body, potentially leading to long-term health issues (DOA, 2020).

The nutrient solution contains essential nutrients required for plant growth. In hydroponics, plants absorb this nutrient solution through their roots, supported by artificial or natural media instead of soil. The composition of the nutrient solution changes substantially based on the plants' uptake needs. Proper nutrient solution management is essential for crop productivity and quality (Savvas, 2002). Recycling the solution multiple times by monitoring and adjusting it before discharge can help prevent water pollution and reduce nutrient waste. Plants are fertilized with a formulated solution containing 10 hydroponic fertilizers supplying 13 essential nutrients. A common issue with this system is that the fertilizer solution is often discarded into drains after each harvest cycle, which may cause irrigation pollution and waste fertilizer that could be reused. There appears to be little or no research on reusing fertilizer solutions in hydroponic systems in Malaysia. Therefore, we conducted this study to investigate changes in water solution quality over three planting cycles. This research aims to help the hydroponic industry improve water quality management and reduce water pollution.

2. Materials and Methods

Figure 1 summarizes the water quality analysis after using fertilizer water during kailan growth in a hydroponic system. Figures 2, 3, and 4 depict the preparation of plant material, the preparation and use of fertilizer water, and the analysis quality.

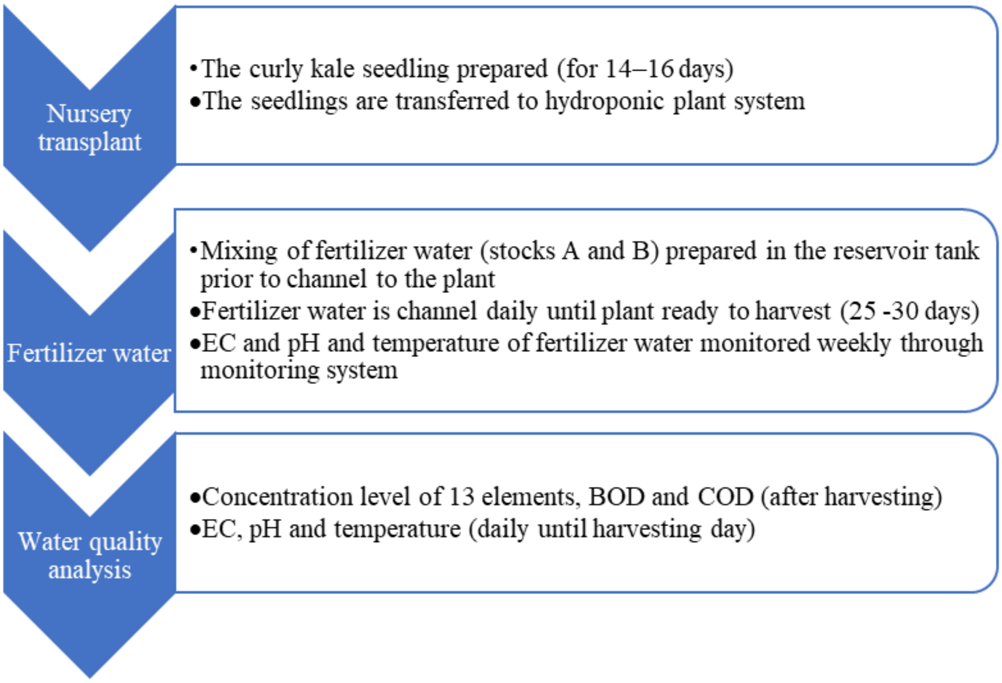

Figure 1. Flow of water quality analysis in the hydroponic system**.**

2.1 Nursery Transplant

The curly kale (kailan) seedling produced two leaves (14–16 days) during germination. Then, the seedlings are transferred along with the germination sponge to the multi-level deep flow hydroponic plant system (DFT) (Figure 2). Plants are planted at a distance of 10 cm in rows and 15 cm between rows. The plant's samples were harvested 25 days after transplanting (DAT).

Figure 2. Hydroponic plant.

2.2 Fertilizer Water

Fertilization will begin once the seedlings are transferred to the crop system. This fertilizer formulation (Table 1) involves 10 types of hydroponic fertilizers that can supply 13 nutrients plants need. For cycle 1, mixing is done in the reservoir tank from the two fertilizer stocks, A and B (Figure 3), before channeling to the plant system according to the weight to get the nutrient concentration as desired until harvesting days. The remaining fertilizer solution is not discarded and is used in cycle 2, where fertilizer from stocks A and B is added and mixed in the reservoir tank. The same procedure as above for cycle three is followed. The concentration of fertilizer given to the plants is according to the plant's growth stage, while the pH of the water is ensured to remain acceptable throughout the plant's growth (Zulhazmi *et al.*, 2022). Monitoring and control systems (Figure 4) are important for crop irrigation and fertilization systems to meet optimal crop needs according to the growth stage. Plants require certain levels of nutrients depending on the plant's growth rate. The irrigation and fertilization system has been installed with pH, EC, and temperature sensors in the irrigation system piping system. These sensors are connected to a supervisory control and data acquisition (SCADA) system that sets EC and pH parameters on the SCADA platform.

Table 1. Hydroponic fertilizer formulation of leafy vegetables for cultivation (Zulhazmi *et al.*, 2022).

	Fertilizer	Fertilizer weight (g) for 100 L of stock
Stock A	Calcium nitrate ($CaNO_3$)	5263
	Forum (Fe)	204

	Fertilizer	Fertilizer weight (g) for 100 L of stock
	Potassium nitrate (KNO_3)	3661
Stock B	Monopotassium sulphate (MKP)	2174
	Magnesium sulphate ($MgSO_4$)	3572
	Cuprum sulphate ($CuSO_4$)	3.85
	Zinc sulphate ($ZnSO_4$)	21.43
	Mangan sulphate ($MnSO_4$)	20.51
	Boron (B)	11.67

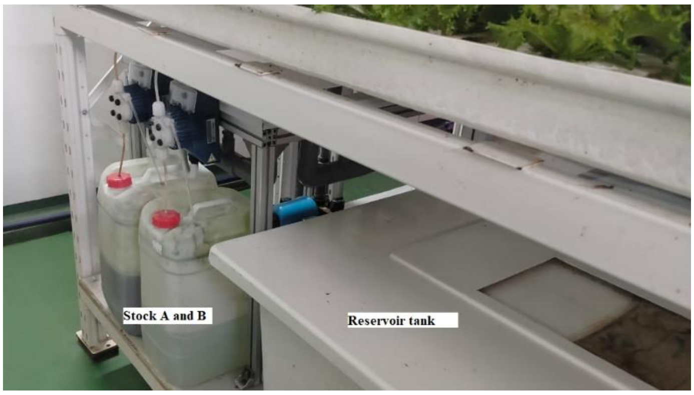

Figure 3. Fertilizer stock A/B and reservoir tank.

The concentration of the nutrient solution was measured weekly using an electrical conductivity (EC) meter. The required concentration level for most plants is between EC 1.5–4.0 µS/m. The frequency of incoming nutrient water can be set on the system panel (Figure 4). In addition, the pH reading is also important in the nutrient solution to balance the acidity level of the nutrient solution. Water temperature and pH have been monitored daily with the help of sensors (Figure 3) (Zulhazmi *et al.*, 2022).

Figure 4. EC, temperature, and pH sensor system.

2.3 Water Quality Analysis

Water sampling activity was carried out at the end of the planting cycle. The samples were collected from the reservoir tank. Water samples for laboratory analysis were collected in 1 liter of HDPE bottles rinsed with deionized water. Samples were taken in triplicates for every sampling session. Samples were immediately analyzed for physicochemical characteristics, while water samples for trace metals were stored in a 4°C chiller in the laboratory.

Before the analysis, water samples had to be filtered using 0.45 µm nitrocellulose filter paper. Chemical water quality parameters involving nutrient Ammoniacal Nitrogen (AN), Phosphate, and Sulphate were analyzed using a spectrophotometer HACH DR 1900. Nutrient analysis was done within 48 hours after sampling. The method for determination of biological oxygen demand (BOD) and chemical oxygen demand (COD) was based on Standard Methods for Examination of Water and Wastewater (APHA, 2005). Trace metals B, Ca, Cu, Fe, K, Mg. Mn, P, and Zn were analyzed using ICP Inductively Coupled Plasma (ICP) Perkin Elmer Optima 7300 DV.

2.4 Statistical Analysis

Each analysis was in 3 replicates. All data were analyzed using ANOVA.

3. Results and Discussions

The results of pH, EC, and temperature (T) of the reservoir tank (cycle 1-3) were demonstrated in Table 2. Temperature in all sampling ranged from 24.56–24.76^{0}C. The pH values ranged from 7.89–8.57, indicating a slightly alkaline pH (>7.0), which means that these waters are suitable for irrigation and within the standard requirements (Ayers & Westcot 1985). The pH value of water suitable for agricultural activities is between 5.0 and 9.0. Water with high acidity will affect plant growth, agricultural equipment, and the application of fertilizers and pesticides. Water that is too high in pH, which is alkaline, will cause calcium precipitation from the water that causes agricultural equipment to clog (DOA, 2020). The EC values average ranged from 1.09–1.62 µS/m, which indicated the source of water is a freshwater type and was at the optimal level for agriculture purposes. An EC value above 3 µS/m is not suitable for plants where it will interfere with water intake by plants (DOA, 2020).

Table 2. Results of pH, EC, and T of fertilizer water for three planting cycles.

Parameter	Cycle 1	Cycle 2	Cycle 3
pH	7.89 ± 0.28	8.57 ± 0.22	8.18 ± 0.17
EC (µS/m)	1.21 ± 0.15	1.62 ± 0.26	1.09 ± 0.09
T (^{0}C)	24.56 ± 0.15	24.75 ± 0.11	24.76 ± 0.10

The analysis results show a comparison of the study's observed values with those recommended by the National Water Quality Standards (NWQS) (DOE, 2017), as shown in Table 3. Class IV, used in this comparison, is the water quality standard for irrigation purposes. AN concentration observed was between 0.0–0.33 mg/L and was below the standard requirement. The highest average concentration was found in sample cycle 2. The concentration of AN was high, possibly due to the accumulation of excess nutrients in the location from aquatic plant activity. Other contributing factors might be aquatic organisms and dead algae (Li & Shen 2013). AN is the product of decomposition of organic matter by bacteria in water; the last is from nitrogen fertilizer in the water. Increased ammonia nitrogen concentration can be a significant environmental factor triggering eutrophication in the water body when nitrogen is the limiting factor (Li & Shen 2013).

Table 3. Results Chemical Water Quality of Cycle 1–3.

Parameter	Cycle 1	Cycle 2	Cycle 3	Class IV NWQS
AN (mg/L)	0.10 ± 0.10	0.33 ± 0.07	0.03 ± 0.01	2.7
Nitrate(mg/L)	0.02 ± 0.01	3.47 ± 0.23	16 ± 3.46	5
Phosphate(mg/L)	9.73 ± 2.97	12.50 ± 1.01	72.3 ± 4.24	NA
Sulphate (mg/L)	67.00 ± 1.00	7.33 ± 2.83	49.0 ± 5.29	NA
B (mg/L)	0.20 ± 0.01	0.34 ± 0.02	0.70 ± 0.01	0.8
Cu (mg/L)	0.04 ± 0.01	0.05 ± 0.01	0.02 ± 0.01	0.2
Zn (mg/L)	0.32 ± 0.01	0.33 ± 0.01	0.2 ± 0.18	2
Mn (mg/L)	0.01 ± 0.01	0.03 ± 0.01	0.01 ± 0.01	0.2
Fe (mg/L)	1.38 ± 0.03	2.54 ± 0.02	10.0 ± 0.05	5
K (mg/L)	206.27 ± 3.94	308.73 ± 3.00	349.9 ± 0.79	NA
Mg (mg/L)	22.87 ± 0.25	54.75 ± 0.44	49.5 ± 0.20	NA
Ca (mg/L)	10.18 ± 0.34	125.11 ± 1.59	91.7 ± 1.51	NA
P (mg/L)	131.87 ± 2.14	56.48 ± 0.58	18.5 ± 0.16	NA
COD (mg/L)	22.63 ± 0.42	19.78 ± 2.64	5.78 ± 0.64	100
BOD (mg/L)	4.91 ± 1.89	1.20 ± 0.10	0.73 ± 0. 23	12

NA = not available; NWQS = National Water Quality Standards for Malaysia

Chemical analysis shows that the concentration levels of AN, B, Cu, Mn, Zn, COD, and BOD obtained from water sampling cycles 1–3 during the end of cycle phases are still within the acceptable range. The determination of the content of some minerals is also relatively low compared to the NWQS value. Although the process of nutrient uptake by plants should have occurred throughout the growth period, observation values have shown that nitrate and metal Fe have exceeded the maximum limit set by NWQS for cycle 3, while for several other parameters such as Ca and Mg. However, there is no fixed value in the NWQS, but it has shown no increase at cycle three compared to cycles 1–2. The water analysis results for cycle 3 show an improvement in several parameters, such as phosphate, sulfate, and K. Increasing values may cause the following effects on water quality: excessive nitrate content, which will encourage eutrophication, and the effect of iron metal toxicity to plants.

COD is a measure of the oxygen equivalent of the organic matter content of a sample that is susceptible to oxidation by a strong chemical oxidant (APHA, 2005). The COD measured for all samples was in the range of 5.78–22.63 mg/L. The highest average COD was recorded at sample cycle 1. All samples value of COD falls below Class IV NWQS (DOE, 2017). BOD measurement for all sampling points was in the range of 0.73–4.91 mg/L. BOD measures dissolved oxygen (DO) concentration consumed by microorganisms as they degrade organic matter. It can be used to conclude the general quality of the water and its degree of pollution by biodegradable organic matter (APHA, 2005). The highest average BOD was recorded in samples cycle 1. Since aquaculture effluent was directly transferred into the irrigation canal, bacteria consumed more oxygen to activate in the oxidation process of organic material. This situation increased the value of BOD in the water. The study's BOD concentration is below the standard Class IV NWQS (DOE, 2017).

4. Conclusions

The concentrations of AN, B, Cu, Mn, Zn, COD, and BOD obtained from water samples in cycles 1–3 during the harvesting phases remain within the acceptable range. Observations for cycles 1–3 show that nitrate and Fe have exceeded the maximum limits set by NWQS. Other elements, such as Ca and Mg, showed no increase in cycle three compared to cycles 1–2, but phosphate, sulfate, and K levels did increase. Measures to control nitrate and other element levels need to be implemented to ensure the safety of both plants and humans. This can be achieved through filtration or other methods.

Author contributions: Concept, methodology, validation, Mohamad Jani Saad, Mohammad Abid Ahmad, Jamaliah Jaafar; analysis, investigation, raw material, data curation, writing preparation of the original draft, Mohamad Jani, Saad, Mohammad Abid Ahmad, Jamaliah Jaafar, Mohd Khairul Anuar Sumadi; writing - comments and editing, Mohamad Jani Saad, Mohammad Abid Ahmad, Jamaliah Jaafar, Norlida Mohamed Hamim.

Funding: MARDI funding (PRH503) was provided for this research.

Acknowledgments: The authors acknowledge the Malaysian Agricultural Research and Development Institute (MARDI) for financial grant no. PRH503.

Conflict of Interest: The author declares no conflict of interest.

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