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Determination of Iron (Fe) and Potassium (K) in Closed Aquaponic Systems by Using Atomic Absorption Spectroscopy and Flame Photometer

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GRAPHICAL ABSTRACT

Prototype of aquaponic systems

ABSTRACT

Aquaponics is the combination of aquaculture and hydroponic cultivation plants. In this study, fish's food and waste were used to develop a sustainable aquaponic system. Hydroponic tank was planted with water spinach (Ipomoea aquatica) that has been used to treat water from an aquaculture system stocked with Koi fish (Cyprinus carpio). The unplanted hydroponic tank was concurrently run as a control unit. The prototype of aquaponic systems was built which consists of fish culture tank, aeration pump and sand medium. The Koi fish were feed three times a week with diet pellets containing 5% of iron concentration. The concentration changes of dissolved iron (Fe) and potassium (K) were the function to increase the biomass of Koi fish by feeding the fish which contributed to the growth of water spinach through aquaculture-hydroponic systems. This observation was monitored for more than 8 weeks. The optimum temperature for aquaponic systems to operate was in a range of 25°C to 29°C. The concentration of Fe^{2+} in water from an aquaponics system was determined using Atomic Absorption Spectroscopy (AAS) while for concentration of K+ ions determined by Flame Photometer. Calibration correlation coefficient value for calibration standard Fe was 0.9999, while for K was 0.9992. The final concentration of K^+ in tank B was 17.1706 mg/L, while in tank C was 17.3402 mg/L. For Fe^{2+} the final concentration in tank C was 0.038 mg/L.

Keywords: Aquaponic, aquaculture, hydroponic, Ipomoea aquatica, Cyprinus carpio

1. INTRODUCTION

Aquaponics is a technique of growing plants hydroponically using nutrients contributed from an aquaculture system. Aquaponics makes multiple usage of resources such as water and nutrients (Vandam *et al*., 2017). Aquaponics can be considered a sustainable agricultural production system as it does not deplete any non-renewable resources that are crucial to agriculture in order to sustain the agricultural practices. In this system, nutrients, which are secreted directly by the fish or generated by the microbial breakdown of organic wastes, are absorbed by plants hydroponically (Akter *et al*., 2018).

Observation about the amount of macronutrients and micronutrients available in aquaculture systems that integrate with plant production within the daily increase of dissolved metabolic by products from fish is necessary to be considered in this study. The amount of feed provided in aquarium tank will affect the fish biomass in aquaponic systems (Diver, 2010).

Increasing fish biomass also signify increasing the total amount of feed provided per aquarium tank, which tends to increase the concentration of dissolved anions and cations involved in the nitrogen and carbon cycles as well as dissolved minerals (macronutrients and micronutrients), such as K^+, Mg^{2+}, Na^+, Fe^{2+}, Cu^{2+}, P and S (Konig, 2016).

The change in nutrient concentration can be influenced by varying the ratios of plants to fish. The relative proportions of soluble nutrients excrete by fish made available to the hydroponic plants do not show the proportions of nutrients assimilated by normally growing plants, the rates of change in concentration for individual nutrients differ (Rakocy *et al*., 1998).

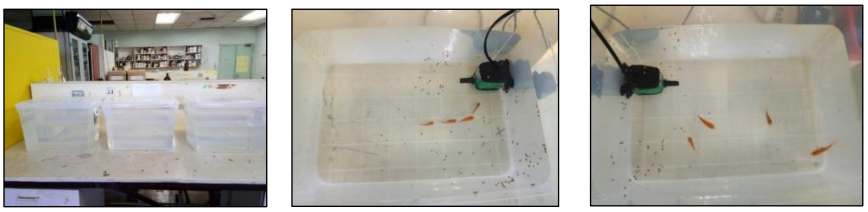
This study was conducted to examine the fish's food and waste to develop a sustainable aquaponic system where the co-cultured organisms, fish, bacteria and plants, should be considered holistically in all aquaponics operations in scope of concentration of Fe^{2+} (micronutrient) and K^+ (macronutrient) in aquaculture systems.

2. EXPERIMENTAL

The experiment was divided into three main stages. The first stage was focused on the setup of aquarium prototypes. The prototype of aquaponic systems consists of fish culture tank, aeration pump and sand-river medium culture. Aquaponic systems used in this experiment present a total volume of 16 L of water, consisting of three aquarium tanks (38 cm × 27 cm × 26 cm) (length × width × height) in tank A, B and C. Hydroponic tank was planted with water spinach (*Ipomoea aquatica*) that has been used to treat wastewater from an aquaculture system stocked with Koi fish (*Cyprinus carpio*).

The unplanted hydroponic tank was concurrently run as a control unit. Once a week sampling of aquarium water (6 weeks). Water sample was taken and measured from each tank at 8-12 cm from the water surface, between 10:00 and 11:00 a.m. using measuring cylinder and transferred into 50 mL bottles sample. The analysis of sample was conducted by using 0.025 L of sample in AAS and flame photometer.

The water samples were used to determine the concentration of Fe^{2+} and K^{+} ions. The fish pellets were weighed 1.0011 g and transferred into 100 mL beaker. In fume hood, 5 mL of H_2SO_4 solution was added into beaker and stirred the solution on hot plate. The solution heated for 5 minutes until fish pellets dissolved. HNO_3 solution was added drop by drop until the gas bubbling subsides and the solution becomes clear although the colour is a little brownish. The solution was transferred into 50 mL volumetric flask and marked up with deionized water. 0.25 mL of concentrated sample was diluted in 50 mL volumetric flask with 200 dilution factors to determine concentration of Fe^{2+} in solution by using Atomic Absorption Spectrometer. For determination concentration of K^{+} by using Flame Photometer, the concentrated solution were diluted into three dilution factors which are 200, 100 and 10 dilution factors.



(a) **(b)** **(c)**

Figure 1. Aquaculture system, a) overall tanks, b) aquarium tank labelled B, c) aquarium tank labelled C

3. RESULTS AND DISCUSSION

3.1. Calibration curve

Plots of absorbance against concentration of standards yield a linear graph for Fe by using Flame Atomic Absorption Spectrometer (FAAS). While for standard solution K, plots of intensity against concentration of standard give a linear graph determine by Flame Photometer. Calculated calibration curves gave good linearity for Fe and K in the low concentration range of 1-10 mg/L with correlation coefficients, r^2 of 0.9999 and 0.9992, respectively.

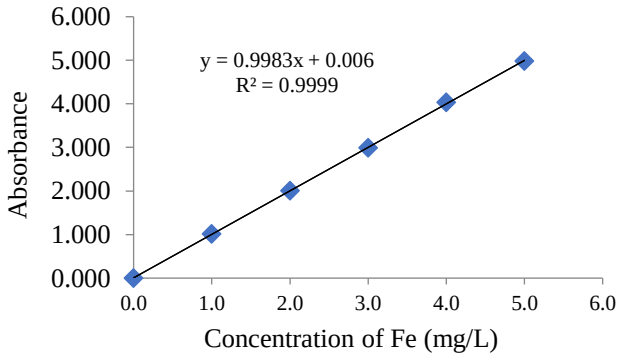


Figure 2. Standard calibration curve for Fe

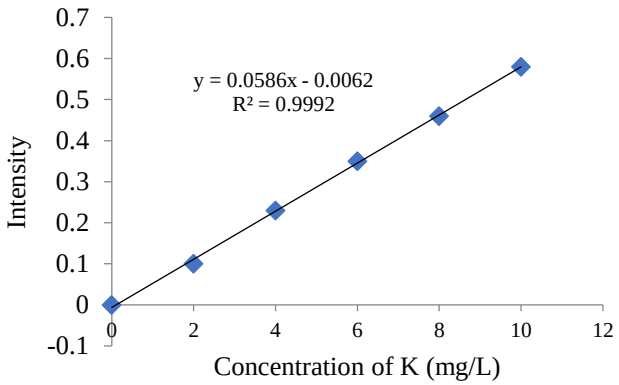


Figure 3. Standard calibration curve for K

3.2. Concentration of Fe^{2+} and K^{+} in commercial diet pellets

The digestion of diet pellets was done by digested 1.0011 g of pellets in 5 mL of H_2SO_4 and drops of HNO_3 until dissolved. According to the commercial diet manufactured analysis, the stated 5% concentration of iron was 20 mg/g. The concentration of K^{+} is 46 mg/g and Fe^{2+} in diet pellets are 0.6 mg/g. The initial concentration of K^{+} and Fe^{2+} in aquaponic volume, 16 L were 2.875 mg/L and 0.037 mg/L respectively.

These concentrations do not affect by any addition of fish, sand, or plants. When the other components were added in aquaponic systems, the concentration will decrease with increment of experimental days. The figure 4 shows the concentration of Fe^{2+} and K^{+} in diet pellets after 200 times of dilution.

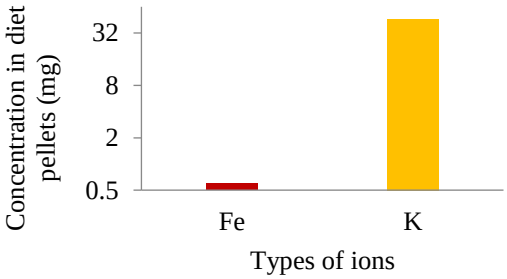


Figure 4. Concentration of Fe and K in commercial diet pellets

3.3. Trend Fe^{2+} and K^{+} in water samples

The record of the nutrient concentration enabled identifying where the nutrients were trapped in the system and which proportion was recycled or lost. The fish nutrient input (commercial diet pellets) was constant during the period of study which allowed drawing a picture of their mass balances. The analysis was conducted by using 0.025 L of water sample each for AAS and flame photometer. The concentration of K^{+} and Fe^{2+} were analyzed in each of tanks at certain setting conditions.

Managing hydroponic nutrients in closed systems by the mass of commercial diet pellets balance approach suggests that once the young plant has taken up a sufficient amount of nutrients, concentrations in the solution can be reduced because a finite amount of required nutrients to grow the crop will be either in the plant or in the solution (Bartelme *et al*., 2018). The use of fish pellets in diets provides highly digestible protein but can contribute higher levels of phosphorus than are needed or can be absorbed by fish. Fish pellets use has raised criticism both because the unabsorbed phosphorus contributes to eutrophication, and, on a global scale, it has been claimed that it results in a net protein loss. Fortunately, most of the unabsorbed phosphorus excreted by fish is in solid form as faeces or uneaten food. Rapid and efficient solid waste removal can reduce the portion of phosphorus discharged before it has the chance to leach out of the solid and become a dissolved form (Thuy *et al*., 2010).

The temperature of aquaculture system constant in a range of 25°C to 29°C. Typically aquaponic operation at a pH of 7.0, whereas plants grown hydroponically prefer a lower pH, from 5.5 to 6.5. In the beginning the conditions were ideal

as water was clean, and no big amounts of wastes were produced yet, and no big densities of microorganisms existed (Tyson *et al*., 2008).

After a period the pH raised dramatically (8.35), which is correlated to the increasing of wastes quantities and microorganisms. The pH kept rising till it reached 8.37 which is a slightly high pH. This is mainly due to the accumulation of wastes and chemicals produced from fish and other microorganisms in water. Nevertheless, a slightly high pH is usually not a problem in this system, because the "Cycling" process is designed to encourage beneficial nitrifying bacteria to take up in the system (Sayara *et al*., 2016).

In this observation, as number of weeks increase, the amount concentration in K^+ in water sample also increase. The figure 4.5 shows the concentration of K^+ in tank B and C. In tank B of aquaponic systems, the initial concentration of K^+ by week 1, week 2, week 3, week 4, week 5 and week 6 that were found in water sample for were 2.8831 mg/L, 5.7732 mg/L, 8.6618 mg/L, 11.5543 mg/L, 14.4437 mg/L and 17.3408 mg/L respectively.

The temperature of aquaculture system constant in a range of 25°C to 29°C. Typically aquaponic operation at a pH of 7.0, whereas plants grown hydroponically prefer a lower pH, from 5.5 to 6.5. In the beginning the conditions were ideal as water was clean, and no big amounts of wastes were produced yet, and no big densities of microorganisms existed (Tyson *et al*., 2008).

The final concentration of K^+ in tank B were observed after some of the concentration absorbed by fish and plant. the final concentration of K^+ by week 1, week 2, week 3, week 4, week 5 and week 6 that were found as 3.3481 mg/L, 5.9078 mg/L, 7.4436 mg/L, 11.0273 mg/L, 14.0989 mg/L and 17.1706 mg/L respectively.

As we can observed, the final concentration of K^+ increase when the initial concentration increase. In week 3, the final concentration of K^+ was more decrease compared in other weeks because in this week, water spinach was added, and assumption can be make here where the absorption of K^+ was highest in plant. The residue concentration of K^+ in week 1 and week 2 were negative values because before any addition of fish and diet pellet, the water itself already contain K^+. The residue concentration in week 3 back to normal when sufficient of addition diet pellets in week 1, week 2 and week 3.

In tank C of aquaponic systems, the initial concentration of K^+ by week 1, week 2, week 3, week 4, week 5 and week 6 that were found in water sample were 2.8836 mg/L, 5.7738 mg/L, 8.6649 mg/L, 11.5555 mg/L, 14.4457 mg/L and 17.3437 mg/L respectively. The final concentration of K^+ in tank C in week 1, week 2, week 3, week 4, week 5 and week 6 were 3.5187 mg/L, 6.0784 mg/L, 8.6382 mg/L, 11.5392 mg/L, 14.4402 mg/L, and 17.3402 mg/L.

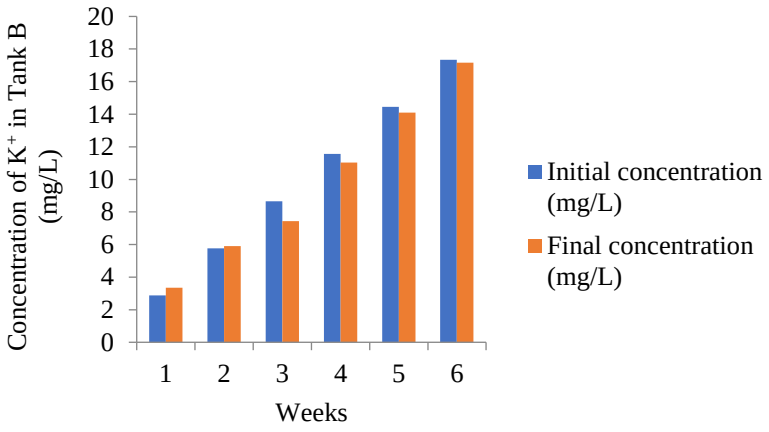


Figure 5. The concentration of K^+ against weeks tank B

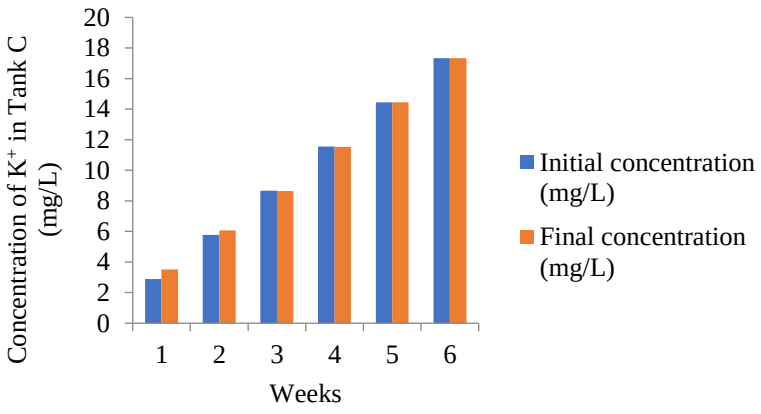


Figure 6. The concentration of K^+ against weeks tank C

The concentration of Fe^{2+} in water sample was recorded and analysed. The volume of water sample used in analysis was 0.025 L. The concentrations of Fe^{2+} in 16 L in each tank were also calculated. The figure 7 and 8 shows the numbers of concentration Fe^{2+} in tank B and C.

In tank B of aquaponic systems, the initial concentration of Fe^{2+} by week 1, week 2, week 3, week 4, week 5 and week 6 that were found in water sample 0.025 L were 0.0376 mg/L, 0.0753 mg/L, 0.1129 mg/L, 0.1507 mg/L, 0.1883 mg/L and 0.2261 mg/L respectively. For the final concentration of Fe2+ 0.047 mg/L, 0.000 mg/L, 0.007 mg/L 0.122 mg/L, 0.000 mg/L 0.000 mg/L.

In tank C, the initial concentration of Fe^{2+} by week 1, week 2, week 3, week 4, week 5 and week 6, that were found in water sample were 0.0376 mg/L, and 0.0753 mg/L 0.113 mg/L, 0.1507 mg/L, 0.1884 mg/L and 0.2262 mg/L respectively. While for final concentration of Fe^{2+} in week 2, 3, 4 and 5 there is no concentration of Fe^{2+}. The final concentration of Fe2+ in tank C of aquaponic systems were 0.038 mg/L. As we can be observed here the tank C had higher number concentration of Fe^{2+} compared in tank B. This indicated the colour of aquaponic water a bit darker in tank C which was shown the accumulation of Fe^{2+} concentration was higher.

Then, after the removal of sand-river medium, the concentration of Fe^{2+} increase rapidly due to the traces of Fe^{2+} contained in sand medium were left into aquaponic water. The residue concentration of Fe^{2+} in fish flesh from tank B were -0.0009 mg/L, 0.0753 mg/L, and 0.1059 mg/L, 0.0287 mg/L, 0.1883mg/L and 0.2261 mg/L with increasing number of weeks. In tank C, the concentration of Fe2+ in fish flesh were 0.0296 mg/L, 0.0753 mg/L, 0.113mg/L, 0.1507 mg/L, 0.1884 mg/L, 0.1882 mg/L.

The concentration of Fe^{2+} in week 4 for tank B is the highest because in this week the plant was introduced into the systems. Plant species used in experiment showed poor growth at 4 week, which might be due to the sensitivity of the root system on nutrients characteristics present in the system Plant has low attraction toward Fe2+ so the concentration of Fe^{2+} in water increases (Rono *et al*., 2018).

The growth of leaves can be limited due to either the low level of photosynthesis or insufficient cell elongation. The cells of leaves are smaller in plants suffering from nitrogen deficiency. These effects arise from the decrease in water conductance which results in water deficiency in the covering of growing leaves (Pantanella, *et al*., 2012).

In this closed aquaponic systems, the water was not change for a long period of time that will contribute to increasing the concentration of ammonia (NH_3). This condition will cause toxicity toward growth of fish. The life span of fish will decrease (Tautkus *et al*., 2004).

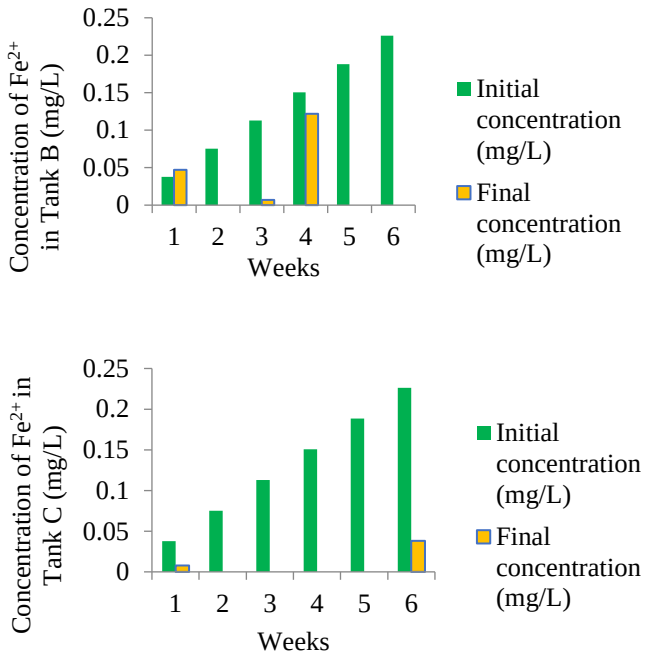


Figure 7 The concentration of Fe^{2+} against weeks in tank B (top) and C (bottom)

4. CONCLUSION

In this study, it is proven that the atomic absorption spectroscopy and flame photometer can be used to determine the concentration of K^+ and Fe^{2+} in aquaponic water systems. The concentration of K^+ is 46 mg/g and Fe^{2+} in diet pellets are 0.6 mg/g. The initial concentration of K^+ and Fe^{2+} in aquaponic volume, 16 L were 2.875 mg/L and 0.037 mg/L respectively. As the number of weeks increase, the final concentration of macronutrient (K^+) and micronutrient (Fe^{2+}) increase in both tanks. The final concentration of K+ in tank B by week 1, week 2, week 3, week 4, week 5 and week 6 that were found as 3.3481 mg/L, 5.9078 mg/L, 7.4436 mg/L, 11.0273 mg/L, 14.0989 mg/L and 17.1706 mg/L respectively, while in tank C were 3.5187 mg/L, 6.0784 mg/L, 8.6382 mg/L, 11.5392 mg/L, 14.4402 mg/L, and 17.3402 mg/L. The low concentration of Fe2+ in tank B found in water which are Fe^{2+} 0.047 mg/L, 0.000 mg/L, 0.007 mg/L 0.122 mg/L, 0.000 mg/L 0.000 mg/L. While for final concentration of Fe^{2+} in week 2, 3, 4 and 5 there is no concentration of Fe^{2+}. The final concentration of Fe^{2+} in tank C of aquaponic systems were 0.038 mg/L. The different number of concentration of K^+ and Fe^{2+} in each tank B and C due under setting condition that and has been setup. The trends of concentration of K^+ and Fe^{2+} can be observed when the plant was introduced in aquaculture systems and after the removal of sand-river medium culture.

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