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Intermittent Water Pump Operation to Reduce Energy Consumption of Aquaponics System

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This research was conducted to investigate the effect of intermittent water pump operation on nutrient uptakes and plant growth yield in an aquaponics system. Four backyard size aquaponic units were build using the same type of hydroponics grower known as media grow bed. Four different types of water circulation system which are, (a) 2 h on and off (2HWC), (b) 4 h on and off (4HWC), (c) 8 h on and 16 h off (8HWC) and (d) 24 h on (24HWC) of the pump were implemented on the aquaponic units. Cocopeat was used as the substrate. A compact water filtration system containing mechanical and biological filtration units was used in this study. Water quality (ammonia, nitrite, and nitrate), plant yield, and fish growth were all measured weekly during the twelve-week experiment. Other parameters measured include pH, water temperature, dissolved oxygen (DO) concentration and total suspended solids (TSS). The result revealed that pH, water temperature, TSS and DO values remain within the acceptable range for growing *Gynura procumbens* (*G.procumbens*) and culturing of *Oreochromis* spp.. A good conversion rate of ammonia into nitrate was obtained using a compact water filtration system. The highest increment in plants height and leaves production could be seen in 2HWC where the percentage of *G.procumbens* growth was 377 % (height) and 960 % (leaves) throughout the cultivation period. The highest yield of fish growth was also found to be in 2HWC (211 %). 31.5 kW (50 %) energy could be saved using 2HWC as compared to the control (24HWC). This result could be used in conserving the energy of aquaponic farm growing herbs and tilapia. Future research needs to be conducted to determine its suitability in conserving the energy of aquaponic farm growing other types of plants and aquatic animals. Lower energy consumption in aquaponics system reduces the high cost associated with small aquaponic farm and increase profit in the long-term run.

1. Introduction

Aquaponics is a method where the recirculating aquaculture system (RAS) and hydroponics were combined in one production system to produce two products (vegetables and fish). It shows the possibility of long-term food production in urban areas (Li, 2018). The basic aquaponics system consists of a fish tank (fish growth), hydroponics grower (plants growth) and filtration unit (beneficial microorganism reside) (Pantanella, 2018). In aquaponics, water is being conserved through the recirculation system as water is being recirculated from the fish tank into the filtration tank. From the filtration tank, the water enters the hydroponics grower and back again into the fish tank. There would be no accumulation of toxic waste (from fish faeces) because the waste produced is being used by the plants for growth (Rakocy, 2012).

The investment cost of building up an aquaponic system is high compared to the conventional or hydroponic method (Turnšek et al., 2019). In aquaponics operation, apart from the necessary installation cost, there are numerous non-sustainable components to its operation that has a significant impact on the aquaponics operational cost. These include the daily fish feeding, water requirements, and the electricity demand for the pump's operation (Love et al., 2015). Typically, for a 6 x 2 m^2 size aquaponics unit, one 100 W submersible pump is needed for water circulation and it usually runs for 24 h. Air pumps are also required to provide adequate aeration for the fish and plants within the system where the dissolved oxygen level in the water should be maintained at 5 $mg \cdot L^{-1}$ or greater (Somerville et al., 2014). The aquaponics system needs electricity to operate

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the pumps and will not work without access to a reliable source of power. In Malaysia, pricing and electrical usage tariff are typically between 0.30 and 0.50 MYR/kWh and it depends on whether the electrical usage is either for residential areas, commercial/industry users or for agricultural purposes. These rates may not be an issue for small scale operators who operates a backyard (or rooftop size) aquaponics set-up. Larger commercial aquaponics farm (i.e. area > 1 acre) and/or for low-income farmers in the rural area including B40 community (i.e. group with household income less than 3,000 MYR/month), such rates could be a burden in their aquaponics operation (Love et al., 2015). Solar energy is a promising alternative to produce renewable electrical energy but the installation cost is very expensive and does not guarantee a 24 h power supply for multiple pumps operation as it is weather dependent (Ahmad et al., 2013).

To date, reduction in electricity consumption for aquaponics operation has not been extensively studied; only a few addresses potential measures for energy-efficient aquaponics systems. Olafs (2014) proposed the use of an airlift system that uses a single air pump for water circulation and aeration purposes. The airlift system was established in a sump tank of the aquaponics unit and was operated intermittently. The proposed concept does not only decrease the capital cost for the installation of the pump but also managed to reduce electricity demands by at least 75 %. Silva et al. (2018) presented the dynamic root floating technique (DRFT) grower as a potential substitute for the classical raft hydroponic grower. By creating an air space between the board holding the plant and the water solution underneath it, passive aeration was successfully achieved. The air pump was not used and oxygenation for plants was achieved through the oxygen roots of the plants. The proposed design has successfully reduced the electricity cost by up to 11.4 %. The solution proposed by both Olafs (2014) and Silva et al. (2018) are viable but requires one to make minor modifications to the aquaponics set-up.

In this work, different combinations of water pump operation are proposed as a mean to reduce the electricity consumption of the aquaponics set-up. Water pumps were operated intermittently (continuous ON-OFF cycle for pump operations) and their impact on water quality and crops production was investigated. The main motivation of the work is to minimise electrical usage as low as possible to reduce electricity cost and also to preserve the environment. Since energy generation is still largely dependent on fossil fuels, even a small reduction in electricity would have a positive impact on the environment (i.e. lower greenhouse gas emission and carbon footprint) (Le et al., 2020).

2. Methodology

2.1 Aquaponics systems

The total footprint for twelve weeks experimental set-ups in this research was approximately 36 m^2 (6 m length x 6 m width) greenhouse that consists of four grow bed media aquaponic systems. The schematic of the aquaponics system is presented in Figure 1. Fish tank (I) served as the foundation of the aquaponics unit. Water was transported from the fish tank to the filtration unit (II) using a 10.4 W submersible pump. The filtration unit used was a combination of the biofilter and mechanical filter in a compact HDPE cylindrical bin (Kamaruddin et al.,2019).The filtration unit contained a single inlet and outlet ports. The bin was divided into two sections which were the mechanical filtration unit and the biofilter at the top of the bin. The biofilter consisted of flower type Bio-balls, cylindrical ceramic Bio-ring and activated carbon as adsorbent (Dong, 2020). A ball valve and one-way valve were used to regulate water flow from the fish tank to the filtration unit at the rate of 1,400 $L.h^{-1}$.

The hydroponic grower (III) was realized using two rectangular shape basins. There was a siphon installed to create a flood-and-drain media bed system. Air was supplied using an air pump connected to air stones located in each component of the system (I, II, III). To minimise excessive heat from direct sunlight and limit algae growth in the system, a 50 % sun shade net was erected on top of the aquaponics unit. In the hydroponic grower section, *G.procumbens* were grown on cocopeat substrates using a polybag (13 cm x 13 cm). The *G.procumbens* were planted once at the beginning of the study and was cultured using a plant stem (10 - 15 cm) with five leaves. *Oreochromis* spp. (~ 75 g) were stocked into the fish tank after the hydroponic grower has been prepared. A standard acclimatisation approach was used prior to stocking of the fish. All fish were fed twice daily (8 a.m. and 4 p.m.) ad libitum with commercial diets (Star Feed TP2). Uneaten feed was taken out from the tanks manually. A drainage valve installed at the bottom of the filtration unit was used to remove the accumulated sludge weekly. Water was added weekly (~ 20 L) into each of the fish tanks to make up for water lost through evaporation and sludge removal.

There were four different aquaponics set-ups based on water pump operations. Water pumps for aquaponics set-ups 1 and 2 were operated intermittently for every 2 h (2HWC) and 4 h (4HWC). The water pump in aquaponics set-up 3 was only operated for 8 h (8HWC) during the day i.e. between 8 a.m. and 4 p.m. and the pump was switched off thereafter. The water pump for aquaponics set-up 4 was operated continuously for 24 h (24HWC) and was used as a control in this energy minimization strategy. The ON-OFF switching sequence of the water pumps was achieved using a control timer switch.

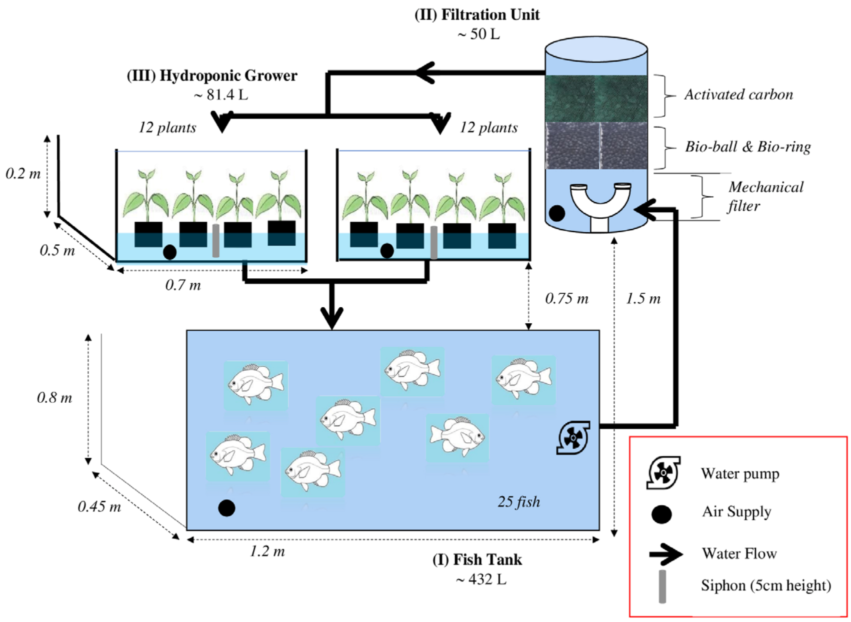

Figure 1: Aquaponics design used in this study

2.2 Data collection and analysis

Water samples (1 L per sample) were taken from the effluent of each tank (fish tank, filtration unit, plant growing area) where various water quality parameters were monitored on a weekly basis. The samples taken were used to measure the temperature, pH, total suspended solids (TSS), dissolved oxygen (DO), level of nutrients such as ammonia (NH_3), nitrite (NO_2^-) and nitrate (NO_3^-). The temperature of the water was measured in-situ using a temperature probe (type K), DO was measured using YSI Model 58 Dissolved Oxygen Meter and pH was measured using a standard standalone meter/probes. The level of nutrients was measured using Hanna Instrument Multiparameter Bench Photometer Model (HI83099-01). As for the determination of TSS, 25 mL of sample was used. The sample was filtered using a weighted standard microfibre filter, and the residue left on the filter was dried for 1 h at 105 °C. TSS was then calculated using Eq(1):

$$\text{TSS (mg/L)} = \frac{[\text{weight of filter and dried residue (mg)} - \text{weight of filter (mg)}] \times 1{,}000}{\text{sample volume (L)}} \quad (1)$$

The height of the plant and the number of leaves produced weekly were used to assess *G.procumbens* growth. Five plants were chosen at random from each of the hydroponic tanks to determine average plant growth. The height of the plants was measured from the plant base to the tip using a standard ruler (Saha et al., 2016). The number of leaves produced by plants was measured by calculating the total number of leaves in a plant. Any recognizable leaves (small or big) were counted (Wood and Roper, 2000).

Fish growth was evaluated based on weight increment for a period of twelve weeks. Five fish were selected at random from each fish tank to measure the average weight every 7 d. Measurements were repeated in triplicate. Percentage (%) of the weight gain was estimated weekly using the Eq(2).

$$\text{\% Weight gain} = \frac{\text{Final weight of fish (g)} - \text{Initial weight of fish (g)}}{\text{Initial weight of fish (g)}} \times 100\ \% \quad (2)$$

The discrepancies between the weight of fish at week 12 and week 1 were used to compute the relative growth rate (RGR) and specific growth rate (SGR) of the fish, using Eq(3) and (4):

$$\text{Relative growth rate (RGR)} = \frac{\text{Weight gain (\%)}}{\text{Duration of experiment (d)}} \quad (3)$$

$$\text{Specific growth rate (SGR)} = \frac{[\text{Ln (Final weight of fish)} - \text{Ln (Initial weight of fish)}]}{\text{Duration of experiment (d)}} \times 100\ \% \quad (4)$$

3. Results and Discussion

3.1 Water Quality of Aquaponics Unit

Table 1 below shows that the result for pH, temperature, total suspended solids (TSS), dissolved oxygen (DO), NH_3, NO_2^- and NO_3^- at all water sampling points were within the desired range (Somerville et al., 2014). TSS and NH_3 level was high at all points (a) compared to others (b and c) due to the presence of fish faeces and uneaten fish feeds. NO_3^- level was the highest at all points (b) due to the presence of nitrifying bacteria in biofilter that converted NH_3 into NO_3^-. NO_3^- level decreased at all points (c) as it was used by plants for growth.

Table 1: The average result of pH, temperature (°C), dissolved oxygen (mg/L), total suspended solids (mg/L), NH_3, NO_2^- and NO_3^- (mg/L) at all water sampling points. (a: effluent of the fish tank; b: effluent of filtration unit; c: effluent of the hydroponic grower).

Parameter	Water Sampling Locations											
	1a	1b	1c	2a	2b	2c	3a	3b	3c	4a	4b	4c
pH	6.6	6.8	6.6	6.6	6.8	6.6	6.6	6.8	6.7	6.5	6.9	6.7
Temperature (°C)	28.0	28.0	28.5	28.0	28.0	28.5	28.0	28.0	28.5	28.0	28.0	28.5
DO (mg/L)	5.8	6.6	7.7	5.3	6.3	7.7	6.0	6.4	7.2	6.1	6.4	7.2
TSS (mg/L)	8.4	2.8	4.6	9.0	2.3	4.4	7.8	2.2	4.4	9.3	2.9	5.3
NH_3	0.3	0.2	0.2	0.2	0.2	0.1	0.3	0.2	0.2	0.3	0.2	0.2
NO_2^-	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.0	0.1	0.1	0.0
NO_3^-	14.9	27.5	19.5	14.9	22.8	18.5	11.7	23.8	16.8	12.8	25.1	19.6

3.2 Effect of Water Circulation Types on Growth of *Oreochromis* spp. and *Gynura procumbens*

Table 2 presents the growth of *Oreochromis* spp. used in this study over 12 weeks of the experiment. The result indicates that the highest percentage of fish weight increment belong to 2HWC (211 %) followed by 24HWC (208 %), 4HWC (206 %) and 8HWC (204 %). There was no difference in the value of water parameters for both treatments (2HWC and 8HWC) except the value of TSS. The SGR is low compared to other study conducted by El-Sayed (2002) or Makori et al. (2017). This might be because the feeding frequency and amount of fed given to the fish are slightly lower than the stated studies. SGR in this study is in range with the study conducted by Hossain et al. (2017), whereby the fish was fed with a diet containing *Spirulina* or an experiment by Nuwansi et al. (2020) which fed the fish twice daily. The SGR in this study is slightly higher than the study conducted by other researchers such as Monsees et al. (2017). 100 % survival rate was obtained in this experiment showing that the water quality and condition of the aquaponics system was being properly set up into favourable *Oreochromis* spp. condition prior to stocking of the fish.

Table 2: Percentage Weight Gain, Relative Growth Rate (RGR), Specific Growth Rate (SGR), Survival Rate of Oreochromis spp. and percentage increment of height and number of leaves for Gynura procumbens for different types of water circulation.

Parameter	Types of water circulation			
	2HWC	4HWC	8HWC	24HWC
Weight gain (%)	211.0	206.0	204.0	208.0
SGR (% per d)	1.4	1.3	1.3	1.3
RGR	2.5	2.5	2.4	2.5
Survival rate (%)	100.0	100.0	100.0	100.0
Increment of height (%)	377.0	357.0	266.0	237.0
Increase in leaves number (%)	960.0	745.0	736.0	867.0

Plants grown using 2HWC showed the highest percentage increased in height and number of leaves. The result showed that increment in the height of plants is inversely proportional to the duration of time the water remains stagnant in the system. 2HWC produce taller plants due to the continuous supply of nutrients to the root of plants and the appropriate period of time given for the plants to absorb the nutrients. At this moment, plants were able to absorb the allocated amount of nutrients. The nutrient would not be depleted as the water will move again after 2 h and supplied the roots with a new amount of nutrients. Besides, 2HWC allowed high hydraulic retention time in the biofilter compared to 24HWC. This gives enough time for nitrifying bacteria to convert NH_3 into NO_2^- and NO_3^-. The system with the longer duration of time water being stagnant in the system (8HWC allowed 16 h water to be stagnant in the system) produce shorter plants. This might be because during 16 h of water stagnant, the level of nutrients available might be depleted and no absorption of nutrients occurred. The result obtained showed that 2HWC was the best water circulation system to produce plants with greater height and high production of leaves.

3.3 Energy Consumption and Saving

Table 3 below shows total power consumption for different types of water circulation over 30 weeks of study. 8HWC led the most energy-saving (34.9 kW) than control (24HWC) as the water pump was ON for only 8 h per day. 2HWC and 4HWC showed the same energy-saving, i.e. 26.2 kW, as compared to the control. Even though 8HWC save energy the most, it does not promote better growth of plants and fish as compared to 2HWC. Among all types of water circulation, 2HWC showed the best performance for the growth of fish (211 % weight gain) and plants (377 % increment in height and 960 % increase in number of leaves). 2HWC also save on 26.2 kW (279.2 kW – 253.0 kW).

Table 3: Total power consumption for different types of water circulation over 30 weeks study.

Parameter		Aquaponics			
		2HWC	4HWC	8HWC	24HWC
Air Pump	Total Hours Operation (h)	24.0	24.0	24.0	24.0
(45.0 W)	Total Power Consumption (W)	1,080.0	1,080.0	1,080.0	1,080.0
Water Pump	Total Hours Operation (h)	12.0	12.0	8.0	24.0
(10.4 W)	Total Power Consumption (W)	124.8	124.8	83.2	249.6
Total Power Consumption per day (W)		1,204.8	1,204.8	1,163.2	1,329.6
Total Power Consumption of the research (kW) (12 weeks X 7 d = 84 d) in triplicate (T)		303.6	303.6	293.1	335.1
Power saving as compared to control (kW)		31.5	31.5	42.0	0.0

Direct electricity consumption is the most significant energy input of aquaponics systems (Atlason et al., 2017). Hence, it is crucial to reduce energy consumption in the aquaponics system. According to Boxman et al. (2017), electricity and feed are the main contributing factors to environmental impacts and suggesting that a slight reduction in electricity could contribute to a correspondingly significant change in the environmental impact. The study conducted by Forchino et al. (2017) underlined the main environmental impacts of aquaponics are related to infrastructures, electricity and fish feed. Forchino et al. (2017) added that reducing water pumping, which is optimizing the water flow, could save energy. Lower electricity consumption caused by reduced aeration intensity and time reduced total GHG (greenhouse gases) emissions which played an essential role in GHG mitigations in aquaponics (Fang et al., 2017).

4. Conclusions

This study demonstrates that water circulation types affect the growth of *Oreochromis* spp. and *G.procumbens* in an aquaponic system. Four different water circulation types (2HWC, 4HWC, 8HWC and 24HWC) were used to regulate water flow in the aquaponics system. An examination of the water quality over 12-weeks revealed that the level of temperature, DO, pH, TSS, NH_3, NO_2^-, NO_3^- were within the acceptable range of *Oreochromis* spp., *G.procumbens* and nitrifying bacteria. There were no signs of nutritional deficits in the plants for all treatment units. Based on the result, water circulation type of 2HWC (2 h water on and off) lead to the production of higher percentage increment in weight of fish (211 %) and better growth of plants (377 % increment in height and 960 % increment in the production of leaves). Energy consumption in 2HWC was half of the control (24HWC) as the water was pumping for only 12 h in total. The growth of crops was better than control. Energy-saving for 2HWC was 31.5 kW as compared to control. In conclusion, intermittent water pump operation was able to lower the aquaponics system's energy consumption. Reduction in energy consumption reduces the environmental impact of aquaponics systems, making it a sustainable method for agriculture. Further study could be conducted on the safety of products (heavy metals and pathogens) grown in the aquaponic system.

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