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Article

Production performance of lettuce (*Lactuca sativa*): aquaponics versus traditional soil

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Abstract: Feeding the ever increasing population in a safe way has become a rising challenge because of reckless use of natural resources. Substitution of traditional farming system with cost effective integration of different production units has emerged as potential solution. In this regards, aquaponics has already put back the traditional farming systems in facing the burning issues of food safety. The experiment was designed to make a comparison of lettuce (*Lactuca sativa*) production between aquaponics (T_1) and traditional soil growbeds (T_2) in laboratory condition at the Aquaponics Laboratory, Bangladesh Agricultural University (BAU), Mymensingh. Each of the treatment has three replications that were placed randomly. A Seven hundred fifty liter water tank was set for fish rearing where 50 tilapia (*Oreochromis niloticus*) and 20 magur (*Clarias batrachus*) fry were released. Tilapia was fed with commercial floating feed while magur with sinking feed. Six (44×26×24 cm3) containers, three for each treatment, were used for lettuce sapling plantation. The fish waste water was irrigated into aquaponics beds and then returned to the fish tank as the thumb role of aquaponics. Fish, plants, water and soil quality parameters were sampled fortnightly, analyzed chemically in the aquaponic laboratory. The results revealed that the performance of $T_2$was better than the T_1 in terms of lettuce growth in respect of plant height, leaf number, plant and root weight. Lettuce production was comparatively higher in T_2 (123.25 tons/ha/89 days), than T_1 (107.89 tons/ha/89 days). This might be attributed to the higher nutrient content of the traditional soil (T_2). At The end of the experiment, the survival rates were 96 and 80% for tilapia and magur respectively whereas the total productions were 47.33 and 4.19 tons/ha/105days respectively. Further research needed to ascertain the superiority of these systems in food production.

Keywords: aquaponics; traditional soil; comparison; lettuce production

1. Introduction

Aquaponics is the integration of recirculatory aquaculture system (RAS) and hydropnics in soilless media utilizing beneficial bacteria for hazard free fish and vegetables production (Normala *et al.*, 2010). This integration involves vegetable production without the conventional soil growbed, stripping toxic metabolites from the recirculating fish waste water as plant fertilizer and providing safe water in return for the fish to live in (Waten and Busch, 1984). In the course of aquaculture intervention, considerable amount of fish wastes are produced in the form of unused feed and excreta that ultimately results in ammonia rich toxic water (Harmon, 2001). For the wellbeing of the fish, this waste water is recirculated through hydroponically (soil free) grown plants' growbed where the residing autotrophic nitrifying bacteria (primarily *Nitrosomonas* and *Nitribacter*) oxidize ammonia into plant usable nitrates (Tyson *et al.*, 2004; Haug and McCarty, 1972). Thus the system render detoxified safe water to fish, lessen aquaculture water use through recirculation, minimize additional fertilizer and pesticide cost for plant production and produce healthy profitable two or more cash crops (Rakocy, 1997; Timmons *et al*., 2002). Indeed, the ever increasing population pressure and resulting scarcity of agricultural land, enormous water use for aquaculture production, adulterated food sources for public health and the overall climate change issues have brought the aquaponics under the limelight (Salam *et al*., 2014a; McMurtry *et al.*, 1997). However, several studies have been conducted to justify the potentialities of aquaponics for healthy food production. In some cases, aquaponics has performed better than the conventional methods by creating ideal environment for fish and vegetable production (Geoff, 2002). A number of leafy vegetables have been tested in aquaponic system, among which lettuce *Lactuca sativa* (Green Oak variety) is a common one because of its wide consumer acceptance. Efficacy of aquaponics over soil or traditional culture method has been under interest of the researchers for decades. Contrary, in Bangladesh, such investigation has not widely been undertaken. Therefore, the present study was conducted with a view to comparing the production performance of lettuce grown in aquaponics and soil (traditional method). The nutrient-flow technique (NFT) was employed to run the aquaponics because of its specific advantages in plant production (Tyson *et al.*, 2001). For fish culture in aquaponics tilapia (*Oreochromis niloticus*) and magur (*Clarias batrachus*) were selected for their suitability in captive culture (Bethe *et al.*, 2017; Tanusri, 2013; Islam *et al.*, 2018).

2. Materials and Methods

2.1. Experimental design

The experiment was carried out for 89 days from 10 December, 2014 to 8 March, 2015 at the aquaponics laboratory, Faculty of Fisheries, Bangladesh Agricultural University, Mymensingh, Bangladesh. Among different types of aquaponic system, media based (NFT) aquaponics was chosen to conduct the present experiment. The design of the study comprised of a fish holding tank (750 L) and six food grade plastic containers (44 ×26 ×24 cm^3) to hold the media (substrate/grow bed). Two types of substrates were used in this experiment namely 100% brick lets and soil separately to assess their performance in terms of lettuce production. Replications of brick lets substrate were indicated as T_1R_1, T_1R_2 and T_1R_3 whereas T_2R_1, T_2R_2 and T_2R_3 were used for soil substrate. Two 10 watt air pumps were used for aerating the fish tank. The waste water from the fish tank was irrigated to the grow bed by a 12 watt submersible water pump. A PVC pipe was connected to each container with another plastic pipe to the outlet pipe for draining the water into the fish tank. Inlet and outlet pipes were set to the tank to facilitate water re-circulation (Figure 1).

2.2. Stocking and rearing of fish

Following complete sanitization, a 750 L plastic water tank (90x51cm^2) was used to stock fish. Bottom of the tank was filled with some cleaned brick lets that provided the fish feel like natural habitat. The tank was fitted with inlet-outlet pipes and two aerators for proper circulation as well as aeration of the tank water. After disinfection with potassium permanganate (2mg/l for 4-5 hours) and acclimatization with tank water, locally collected healthy fifty tilapia (*Oreochromis niloticus*) and twenty magur (*Clarias batrachus*) fingerlings were stocked in the tank. The feed was supplied to the fish twice daily, in the morning at 9.00 am and afternoon at 5.00 pm initially at the rate of 10% magur fish body weight and 5% tilapia fish body weight during the first month and then the rate reduced to 5% and 3% for magur and tilapia respectively. Floating feed was used for feeding tilapia and sinking feed for magur.

2.3. Bed preparation for lettuce culture

Locally available six plastic containers (44×26×24 cm^3) with upper side cut were used for lettuce culture as growbeds. Three containers used for aquaponics (T_1) where brick lets were used as bedding materials. The rest three containers, for traditional culture, were filled with crushed soil (T_2) each mixed with 300g lime, 250g flour, 250g mustard oil cake, and 50gm each of molasses, urea, TSP and potash. The aquaponics (T_1) growbeds were connected each with the fish holding tanks through PVC pipes to facilitate recirculation. After preparing grow beds, four healthy lettuce saplings were planted in four vertices of each container counting twenty four saplings in total in six different containers. Initially height of plant, leaf number of each plant, height of leaf and width of leaf were recorded. Fish tank waste water was used for watering plants in aquaponic system (T_1) through a porous PVC pipe all the day except night whereas tap water was used for traditional soil beds (T_2). As no fertilizer was used in the aquaponic growbeds (T_1), plants' growth was slow for initial 10-15 days and then started at full swing with the growth of nitrifying bacteria.

2.4. Collection of data

Sampling was done fortnightly for the fish, plants, tank water and soil. For fish, sampling was done using scoop net. Ten tilapia and five magur were used to catch randomly for measuring length and weight by using an electronic compact balance (KD-S/F-en) and a cm scale during each sampling and then put back to the tank.

Growth perameters of the fish was measured in terms of mean length and weight gain, feed conversion ratio (FCR), production and survival rate following standard mathematical procedures.

In order to assess the lettuce production performance in both the systems height of individual plant, leaf length and width, leaf area and number were measured fortnightly using an electronic compact balance (KD-S/F-en), a cm scale and an automatic digital electronic portable leaf area meter (Model LI-3100, Lincoln, NE-68504, USA). At the time of final harvest, the leaves and root weight and the total biomass content of lettuce were recorded.

During each sampling, water quality parameters such as Dissolved oxygen (DO), temperature and pH of inlet (from fish tank to aquaponics growbeds) and outlet (from aquaponics growbeds to fish tank) water were measured with the aid of "hanna instruments water quality testing kits". The chemical parameters of water and soil such as nitrite, nitrate, iron, phosphate, available phosphorus (P) and sulphur (S), exchangeable potassium (K) and sodium (Na) contents were measured with standard laboratory analysis procedure followed by Salam *et al*., 2014a.

2.5. Data analysis

Collected data were recorded in a notebook and then loaded in the computer for statistical analysis. One way ANOVA and Duncan's New Multiple Range Test (Duncan, 1955) were employed to test the significance of variation between the treatment means. All statistical analyses were carried out by MS Excel 2007 version and Excel-Stat software. The results have been presented in tabular and graphical forms.

3. Results and Discussion

3.1. Water and soil quality parameters

The water quality parameters of the fish tank remained within the suitable range for aquaculture. As observed, the mean pH value in fish tank water was 7.58 ±0.21 that was within the acceptance level of both tilapia and magur (Swingle, 1968; Chervinski, 1982; Tanusri, 2013). In aquaponic system, nitrifying bacteria require pH within 7.2 to 8.2, whereas nitrification is subdued below the pH value of 5 (Villaverde *et al.*, 1997). The reported mean dissolved oxygen content (DO) in the tank water over the study period was 4.3±1.2 ppm suggesting slightly lower value than ideal condition (DoF, 1996), although within the tolerance range of tilapia and magur (Balarin *et al.*, 1986; Islam *et al.*, 1986). The nitrifying bacteria (*Nitrosomonas* and *Nitrobacter*) resided on the root systems of aquaponic plants could have contributed to oxygen depletion through water recirculation (Sutton *et al.*, 2006). As the present experiment was conducted in the winter season (December to March) the average temperature was slightly lower that varied from 17° to 23.5°C. Nevertheless, this temperature was quite suitable for fish culture as magur grow well within this range (Tanushri 2013) and the lethal temperature threshold for tilapia is below11° C and above 42°C (Balarin *et al.*, 1986). Moreover, temperature range of 7 to 35°C is needed to keep the nitrifying bacteria active in aquaponic system that was avail during the study period (Wortman and Wheaton, 1991).

The results of laboratory analysis of inlet water (waste water from tank to growbeds) and outlet water (recycled water from growbeds to tank) showed that the overall mineral contents of the outlet water were lower than that of inlet water that admit the findings of Salam *et al.,* 2014b. The result implies that the minerals in the form of iron, phosphorus and nitrogen were high in fish tank waste water (Table 1). When this water was re-circulated through aquaponics growbeds, the nitrifying bacteria acted to convert the non edible form into consumable nutrients like nitrates for the lettuce plants. Thus the process renders the system hazard free.

Similar to the findings of Salam *et al.,* 2014a, the biochemical analysis of aquaponic tank water in T_1 and growing soil media in T_2 revealed that the soil growbeds were much nutrient dense compared to aquaponic growbeds hence favorable for better production (Table 2).

3.2. Fish Growth and production

In this experiment, 50 tilapia and 20 magur fry were stocked in a plastic water tank (750 liter) and reared for 105 days. Because of its hardy, high yielding and omnivorous nature tilapia has become a common candidate in aquaponic system (Childress, 2003). The initial mean length and weight of the experimental tilapia were 13.74 (±1.77) cm and 51.13 (±22.27) g respectively that were increased to 16.69 (±2.60) cm and 125.04 (±38.22) g at the final harvest having the length and weight gain of 2.95 (±.83) cm and 73.91 (±15.95) g respectively. Watanabe et al., 2004 and Licamele, 2009; of the University of Arizona reported that mean weight gain of tilapia was 85.39 (±12.04) g after 180 days of rearing. Therefore, weight gain of tilapia was quite satisfactory in this study that might be due to better management practice, good quality feed and suitable temperature over the period. The FCR value of tilapia was 2.54 that is better than the reported FCR value (2.67) for tilapia in aquaponic system of Salam *et al.*, 2014b. Here, survival rate of tilapia was 96% that outweighed the findings of Salam *et al.*, 2013 who recorded 93% survival rate. At the end of the experiment, total production of tilapia was 3.55 kg in 750 L tank which would be 47.30 tons/ha/105 days that surpassed the findings of Rana *et al*., 2015; who obtained tilapia production of 28 tons per hectare for 90 days rearing in ponds. The present finding is comparatively higher than the conventional semi intensive system.

To utilize the bottom space of the fish tank magur fry was released because of its high stocking density tolerance. The initial mean length of magur was 8.43 (±0.71) cm and the final mean length was 15.63(±1.08) cm with the length gain of 7.2 (±.37) cm at final harvest. Hasan, 2014; reported that mean length gain of magur at the harvesting time were 17.80 (±0.09), 13.50 (±0.05) and 12.37 (±0.02) cm in T_1, T_2 and T_3 respectively which were slightly higher than the present finding. The mean weight gain of magur in this study was 19.64(±3.39) g while the initial and final mean weight of fish were 3.78(± 1.00)g and 23.42(± 4.39)g respectively that also conforms with the findings of Hasan, 2014. In the present study, the observed FCR value of magur was 2.84. Tarnchalanukit *et al.*, 1983; estimated the FCR value of *C. batrachus* 1.24-1.32 in circular tank receiving high quality feed whereas Azimuddin *et al.*, 1998; reported FCR from 1.73 to 2.04 for magur fed formulated feed. Thoses were little bit lower than the value of present experiment that might because tilapia and magur were combined cultured in the tank, hence tilapia consumed magur feed so FCR of magur was little bit high. The observed survival rate of magur was 80% that complies with Tarnchalanukit *et al*., 1983; who reported 79.53% survival rate of *C. batrachus*. In winter season, 0.314 kg of magur was obtained from 0.75 m^2 area using plastic drum. If we convert the area in hectare then the total production of fish would be 4190kg/ha/105 days. The present finding was comparatively higher to the finding of Tanushri, 2013 who recorded the production of 382.11and 222.07 kg /ha/113 days respectively. Indeed tilapia and magur performed well in the system (Table 3, Figure 2 & 3).

Table 1. Mineral contents of inlet and outlet water on different sampling dates.

	Inlet water				Outlet water			
Sampling Date	**Fe (ppm)**	**PO_4 (ppm)**	**NO_2 (ppm)**	**NO_3 (ppm)**	**Fe (ppm)**	**PO_4 (ppm)**	**NO_2 (ppm)**	**NO_3 (ppm)**
9/12/2014	0.08	2.28	7.65	0.33	0.05	1.95	4.41	0.20
27/12/2014	0.06	2.16	7.55	0.34	0.04	1.85	4.31	0.10
10/1/2015	0.04	2.40	7.75	0.32	0.06	2.05	4.51	0.30
28/01/2015	0.07	2.28	7.65	0.33	0.05	1.95	6.00	0.10
16/02/2015	0.02	2.40	7.60	0.34	0.06	1.90	3.00	0.20
6/3/2015	0.05	4.00	5.00	0.30	0.07	4.00	12.00	0.50
Mean	0.05 (±0.02)	2.59 (±0.70)	7.20 (±1.08)	0.33 (±0.2)	0.06 (±0.01)	2.28 (±0.84)	5.71 (±3.23)	0.23 (±0.15)
Significant	NS*	NS*	NS*	NS*	NS*	NS*	NS*	NS*

*Non significant when P<0.05

Table 2. Mineral contents of aquaponics water and soil of traditional growbeds.

Treatments	**P (ppm)**	**K (ppm)**	**S (ppm)**	**Na (ppm)**
T_1 (Aquaponics)	2.25 (±0.63)	7.35(±0.75)	2.82(±0.39)	22.17(±1.23)
T_2 (Soil)	23.79 (±2.76)	118.64(±3.38)	51.38(±2.52)	231.65(±3.29)

Table 3. Comparative growth performance of tilapia and magur.

Growth Parameter	**Tilapia**	**Magur**
Mean Initial Length(cm)	13.74(±1.77)	8.43(±0.71)
Mean Final Length(cm)	16.69(±2.60)	15.63(±1.08)
Mean Length Gain(cm)	2.95(±.83)	7.2(±.37)
Percent Length Gain (%)	21.47	85.00
Mean Initial Weight(g)	51.13(±22.27)	3.78(± 1.00)
Mean Final Weight(g)	125.04 (±38.22)	23.42(± 4.39)
Mean Weight Gain(g)	73.91(±15.95)	19.64(± 3.39)
Percent Weight Gain (%)	144.55	519.00
Survival Rate (%)	96.00	80.00
FCR	2.54	2.84
Production (tons/ha/105days)	47.33	4.19

Table 4. Production performance of lettuce in Aquaponics (T_1) and traditional soil (T_2).

	Plant height (cm)		Leaf length (cm)		Leaf area (cm^2)		Leaf number		Leaf weight (g)	
Sampling Date	T_1	T_2	T_1	T_2	T_1	T_2	T_1	T_2	T_1	T_2
10/12/2014	5.13 (±0.64)f	5.17 (±0.8)f	5.07 (±0.7)e	5.07 (±0.74)c	11.88 (±3.3)f	12.97 (±4.1)d	3.08 (±0.5)d	3.08 (±0.5)d	-	-
09/01/2015	23.61 (±1.84)e	27.14 (±2.78)e	15.02 (±1.7)d	17.64 (±2.13)b	66.67 (±12.2)e	119.05 (±51.9)c	5.5 (±1.0)d	6.66 (±1.0)cd	1.14 (±0.30)c	2.19 (±1.3)d
25/01/2015	38.37 (±3.63)d	38.38 (±2.28)d	17.33 (±1.5)c	20 (±2.59)ab	85.82 (±19.0)d	134.96 (±47.9)bc	10 (±2.3)c	11.17 (±2.3)bc	1.30 (±0.40)c	2.75 (±1.7)cd
09/02/2015	60.33 (±9.26)c	50.81 (±6.11) c	19.5 (±1.2)b	20.4 (±2.46)a	103.44 (±13.2)c	152.19 (±21.9)bc	13.92 (±4.1)bc	14.67 (±3.9)b	2.39 (±0.60)b	4.13 (±1.9)c
24/02/2015	77.33 (±15.43)b	63.38 (±10.06)b	21.19 (±1.8)a	22.43 (±3.78)a	163.02 (±39.7)b	166.18 (±23.6)b	17.58 (±7.1)ab	21.5 (±9.7)a	5.97 (±1.4)a	5.64 (±1.6)b
01/03/2015	89.83 (±18.27)a	72.75 (±12.33)a	22.1 (±2.0)a	22.05 (±5.06)a	195.82 (±46.6)a	215.23 (±30.0)a	20.92 (±8.4)a	25.08 (±11.1)a	6.49 (±1.9)a	7.14 (±2.0)a

Values in a row having similar letter (s) or without letters do not differ significantly whereas values bearing the dissimilar letter (s) differ significantly ($p<0.05$) as per Duncan Multiple Range Test (DMRT)

Table 5. Lettuce root length, weight and total production at final harvest.

Treatments	Root length (cm)	Root weight (g)	Lettuce production (tons/ha/89days)
T_1	13.63	14.37	107.89
T_2	12.15	12.86	123.25

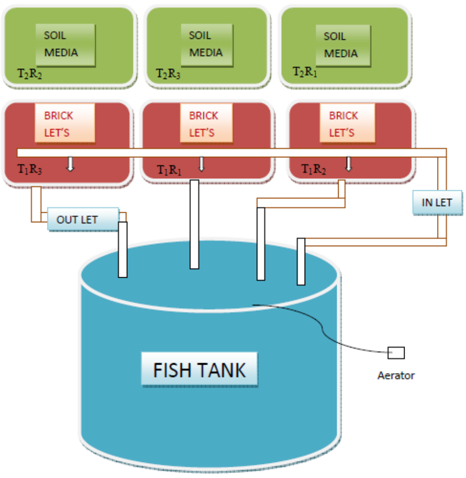

Figure 1. Layout of the experiment.

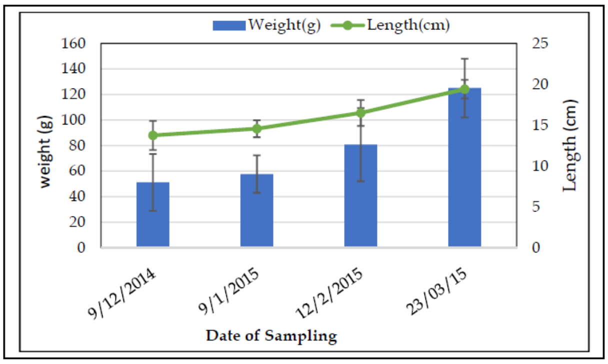

Figure 2. Length (cm) and weight (g) of tilapia on various sampling dates.

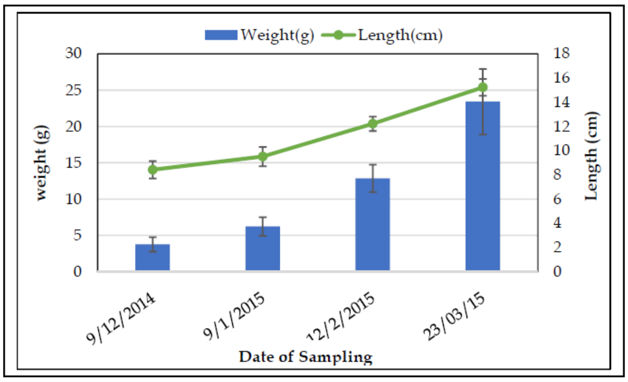

Figure 3. Length (cm) and weight (g) of magur on various sampling dates.

3.3. Lettuce growth and production

During the study, the growth and production performances of lettuce in two treatments T_1 (Aquaponics) and T_2 (Soil) were recorded. The highest mean plant height was 89.83 (±18.27) cm in T_1 and 72.75 (±12.33) cm in T_2 although the differences in plant height among the two treatments on each sampling were insignificant ($P<0.05$). Mader, 2012; found the average height of lettuce were 7.34 cm in the soil, 6.52 cm in the gravel, and 5.7 cm in the which was comparatively lower than the present findings. Interestingly there was no significant difference among the observed data for final average leaf length and leaf area in two different treatments but T_2 performed slightly better than T1 (Table 4). The highest mean leaf number was 25.08 (± 11.1) and it was found in T_2. At that time mean leaf number in T1 was 20.92 (± 8.49) that was not significantly different ($P<0.05$). The highest mean leaf weight in T_2 was 7.14(± 2.0) g whereas in T_1 was 6.49 (±1.9) g. Previous study of Mader, 2012 also reported different leaf weights for different growbeds such as 2.07 g in soil, 1.52 g in gravel, and 0.84 g in fiber. Because of having adequate space in brick-lets growbed, aquaponic lettuce (T_1) attained the highest root length of 13.63cm than in soil (T_2) counted 12.15cm (Table 5). This finding also follows the pattern of Mader, 2012. After the final harvest, the highest estimated lettuce production of 1410.76 g (1410.76g/0.114m2/89 days or 123.25 tons/ha/89 days) was obtained from T_2 whereas T_1 produced 1234.23 g (1234.23g/0.114m^2/89 days or 107.89 tons/ha/89 days) of lettuce although the difference was statistically insignificant ($P<0.05$). However, in this study traditional soil preformed better that is similar to the previous study (Mader, 2012). In contrast, Salam et al., 2014a; concluded differently where aquaponics performed better than soil and hydroponics respectively. In this experiment maximum mineral contents, essential for plant growth, were found in traditional soil media (T_2) that might has outweighed the synergistic effect of aquaponics (T_1) in lettuce production (Rakocy *et al.*, 2004).

4. Conclusions

Food safety in public health is a burning issue now-a-days all over the world including Bangladesh. Aquaponics has already proved its potentiality in providing hazard free healthy fish and vegetables. Comparison of the traditional farming with aquaponics may lead to greater adoption of the aquaponics system in public and private sectors. Although the production of lettuce was not greater than the traditional farming in soil but the products of aquaponics were fully free of fertilizers, insecticides and other hazardous chemicals that are conventionally being used in traditional farming. Thus the benefit of having organically produced safe food from aquaponics can easily outweigh the production benefit of traditional farming. However, further studies are needed to justify more clearly the superiority of the aquaponic system the traditional one.

Conflict of interest

None to declare.

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