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The effect of stocking density ratio of fish on water plant productivity in aquaponics culture system

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Abstract. *Andriani Y, Dhahiyat Y, Zahidah, Zidni I. 2016. The effect of stocking density ratio of fish on water plant productivity in aquaponics culture system. Nusantara Bioscience 8: xxxx.* This study aims to determine the productivity of water plants at various stocking density ratios in the aquaponic culture system. This study is conducted experimentally using the Completely Randomized Design with the differences in the treatment of stocking density ratio, each repeated five times. The treatments of the stocking density ratio of both the catfish fry and the Nile tilapia fry include: A (75:75 fry/m^2), B (100:50 fry/m^{2,} and C (125:25 fry/m^2). The observed parameters are 1) plant productivity including measuring the growth of water spinach and growth rate, covering weight gain, stem length and number of leaves, and 2) water quality, including dissolved oxygen (DO), nitrate and phosphate. The data of plant productivity is analyzed descriptively while the water quality is analyzed using ANOVA. The result of this study shows that the stocking density ratio significantly affects the productivity of water plants and the water quality of the media. The highest productivity of water spinach productivity occurs at the stocking density ratio of 75 catfish fry/m^2: 75 Nile tilapia fry m^2, at which the average stem length is 59.14 cm, average number of leaves is 13.67, and the harvest weight is 465 g. Fish stocking density ratio also affects the quality of water, where the synergy between fish farming and water plant growing results in the better water quality compared to fish farming without water plant. The highest quality of water is achieved at the stocking density ratio of 100 catfish fry/m$^{2:}$ 50 Nile tilapia fry/m^2.

Keywords: Catfish fry, Nile tilapia fry, water plant productivity, water quality

INTRODUCTION

The availability of land and water for aquaculture processing is getting more limited due to population growth and physical development. This calls for innovation in technology to anticipate the decrease of aquaculture products caused by the loss of land for culturing and deterioration of water quality. A technological innovation already available is the integration of fish breeding and planting through the aquaponics system (Diver 2006). The aquaponics system is capable of growing plants, such as lettuce and water spinach, for both the nutritional needs of the fish and edible vegetables for people, thus providing food efficiently by making use of the limited availability of land.

The productivity of water plants and the quality of water for culturing are influenced, among others, by the stocking density ratio in the culture media, in order to achieve an ideal combination for a useful biological control. The results of fish metabolism in forms of ammonium (NH^{4+}), nitrate (NO^{3-}) and phosphate can be utilized by the water plants to reduce the percentage of nitrogen in the media (Rakocy 2007), as well as to increase the growth level of the water plants.

In order to determine the level at which the stocking density ratio of fish influences the productivity of the water plants, an experiment is required in which polyculture of catfish fry and Nile tilapia fry of a certain ratio is conducted, in synergy with the growing of water spinach (*Ipomoea aquatica* Forsk.) and lettuce (*Lactuca sativa* L.) in an aquaponics system.

MATERIALS AND METHODS

Study area

The materials used in this study are: (i) 2,100 Sangkuriang catfish fry aged 54 days with the average weight of 3.07 g, (ii) 1,050 Nile tilapia fry weighing around 4-5 g obtained from Fish Hatcheries (Balai Benih Ikan) in Ciparay, Bandung District, West Java, Indonesia, (iii) water spinach shoots 7-10 cm in height, seeded at Ciparanje pond and lettuce plants of 5-7 cm in height obtained from PT. Momenta Agrikultura "Amazingfarm" Lembang, West Bandung District, West Java, Indonesia and (iv) fish feed in the form of commercial pellets with crude protein contents of 31-33%.

The research method used in this study is the experimental Completely Randomized Design (CRD) method with the factorial pattern of (3x3): factor I fish stocking density ratio (3 levels) and factor II water plant species (3 levels), each repeated three times. The treatment design is listed in Table 1.

Factor I is the stocking density ratio of fish in polyculture (A) at the following levels: (i) a1: Stocking density ratio 150 fry/m^2 (75 catfish fry + 75 Nile tilapia fry), (ii) a2: Stocking density ratio 150 fry/ m^2 (100 catfish fry + 50 Nile tilapia fry), (iii) a3: Stocking density ratio 150 fry/ m^2 (125 catfish fry + 25 Nile tilapia fry).Factor II is the species of water plant (B) which consists of: (i) b1: Water spinach, (ii) b2: Lettuce, (iii) b3: No plant (control).

The model employed in this study is a linear model using the following formula (Gaspersz 1991):

$$Y_{ijk} = \mu + A_i + B_j + AB_{ij} + \grave{\varepsilon}_{(ij)k}$$

Where,

Y_{ijk} = observation value of experiment k undergoing treatment combination ij (level I of factor I (Stocking density ratio), level j of factor II (water plant species).

μ = median of population (average value)

A_i = influence of additive level I of factor I

B_j = influence of additive level j of factor II

AB_{ij} = influence of interaction of level I factor I, level j factor II

$\grave{\varepsilon}_{(ij)k}$ = influence of error of the experiment unit k undergoing treatment combination (ij)

Procedures

Aquaponics system design

This study employs 21 units of fiber troughs filled with water at 40 cm height and aeration installed. These troughs are arranged randomly following certain treatments. The stocking density in each trough is adjusted according to the treatments and their repetition. The water spinach and lettuce growing on culture media are transported to the growing media (styrofoam). The initial length is measured and the number of shoots is calculated for both the water spinach and lettuce; each growing media is filled with the same number of plants for the purpose of convenience in observation during experiment.

The aquaponics system is designed around the *Floating Raft System* by placing the styrofoam boards floating on the fish growing pond (Figure 1).The culturing of both the fish and plants are conducted outdoor.

Implementation

The study is conducted for forty-nine days. Feeding is conducted three times a day at 08.00, 14.00 (02.00 pm) and 20.00 (08.00 pm) with the mass of feed four percent from the total fish biomass. Measuring of water spinach and lettuce is conducted once every seven days in each treatment; measuring includes the weight gain, the length of stem and the addition of new leaves. Measuring the quality of water for the parameters including nitrate and phosphate is conducted once every seven days while measuring DO is conducted both in the daytime and at night. The parameters measured in this study include (i) Plant productivity, which covers plant weight gain, the length of stem and the addition of new leaves, and (ii) Water quality, which covers dissolved oxygen (DO) contents, nitrate, and phosphate.

Data analysis

The data of water plant productivity is analyzed descriptively while the data of water quality is analyzed using the F test. If the difference between treatment occurs, a Duncan Multiple Range Test is conducted at 5% degree.

Table 1. Treatment design

Stocking density ratio (fry/m^2)	**Biofilter type**		
	Water spinach	**Lettuce**	**No plant (control)**
(a)	**(b_1)**	**(b_2)**	**(b_3)**
75 catfish+75 nile tilapia /m^2 (a_1)	a_1b_1	a_1b_2	a_1b_3
100 catfish + 50 nile tilapia /m^2 (a_2)	a_2b_1	a_2b_2	a_2b_3
125 catfish + 25 nile tilapia /m^2 (a_3)	a_3b_1	a_3b_2	a_3b_3

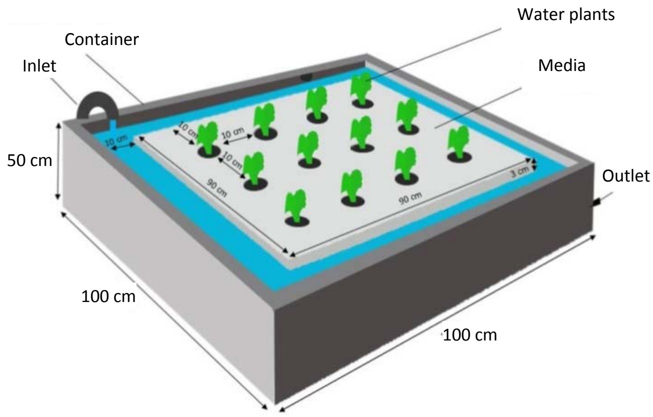

Figure 1. Aquaponics system design

RESULTS AND DISCUSSION

Water plant productivity

During the forty-nine days of growing, increases in stem length, number of leaves and weight occur in each treatment (Table 2). In the second week, the lengths of water spinach stems are around 24.53-31.70 cm.

Water quality

The result of observation shows that the species of plant and differences in stocking density ratio influence the contents of dissolved oxygen (DO) in the media. The values of DO in all treatments are around 4.3-7.6 mg/L. The presence of water plants heightens the concentration of DO more significantly compared to the media without water plants. The fluctuation of DO during the study can be seen in Figure 2.

The other condition of water quality which affects the productivity of water plants is nitrate, that is an important nutrient in the formation of leaves and trunks. Result showed that nitrate concentration in water fluctuated in line with the treatment. The consumption of nitrate by water plants was proven by the differences in nitrate concentration in the water. The medium with plant showed lower nitrate concentration than that without plant (Figure 3).

Table 2. Plant productivity in various stocking density ratios

Production parameter	Water plant species					
	Water spinach			Lettuce		
	75C+75N	100C+50N	125C+25N	75C+75N	100C+50N	125C+25N
Length of stem (cm)	59.14	48.31	55.78	21.88	22.68	23.51
Number of leaves	13.67	10.85	13.52	6.44	6.63	6.29
Weight (g)	465	343.71	435.96	311.94	372.66	445.44

Legend: C = catfish, N = Nile tilapia

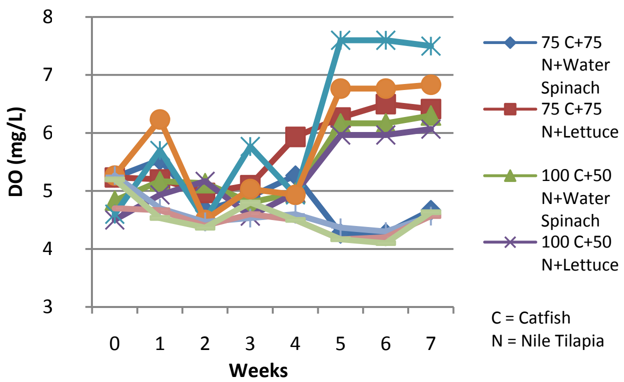

Figure 2. Fluctuation of DO during study

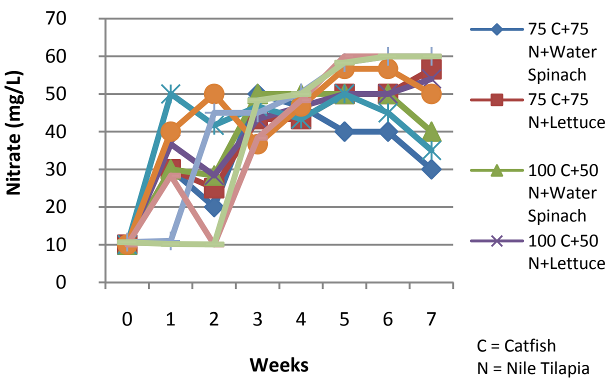

Figure 3. Nitrate concentration during study

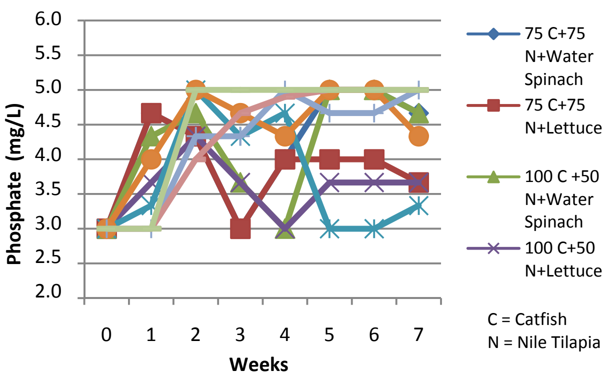

Figure 4. Phosphate concentration change during study

Phosphate is another nutrient that affects plant productivity. The phosphor in the form of phosphate is a micronutrient needed by and highly essential for aquatic organisms including water plants. The phosphate concentration during the study is around 3.0-5.0 mg/L (Figure 4).

Discussion

The result shows that in the aquaponics system, water-spinach can be harvested on the twelfth day, due to the length of the stem has already reached 20-25 cm, which means that during seven weeks of observation the water-spinach can be cultured three times. Meanwhile, on lettuce the harvesting size was reached at the fourth week with average length 27.28 cm. According to Izzaty (2006), marketable size of lettuce ranges between 27-30 cm, which show that lettuce cultivation in aquaponics system during seven weeks of observation can be cultured twice.

Based on the volume of crops produced, it appears that the productivity of the plant in the aquaponics system is lower compared to hydroponics. According Bittsanskzky et al. (2016), most plant nutrients were at significantly lower concentrations in the research aquaponics systems as compared with the standard hydroponic solutions. The differences were highest in the case of Fe^{2+} and Mn^{2+} (with ratios of 68.5 and 138.7, respectively). Fish density also affects the availability of nutrients for plants in aquaponics system. The results of the study Villarroel et al (2011) states that the total amount of feed required per mEq at the low biomass (2 kg fish/m^3) ranged from 1.61-13.1 kg for the four most abundant ions (NO^{3-}, Ca^{2+}, H_2PO^{4-} and K^+), suggesting that it is feasible to integrate fish culture (at low densities) to reduce the cost of the hydroponic solution supplementation for strawberries. The nutritional requirements vary with variety, life cycle stage, day length, and weather conditions. However, the use of lettuce and kale in this study had an appropriate selection. Provided that the system is stocked with enough fish, it is not necessary to add nutrients for plants with short cropping cycle which do not produce fruits (e.g. lettuce). In contrast to, for example, lettuce, tomatoes which need to bear fruit, mature and ripen, need supplemental nutrients.

The results showed that the frequency of crops is higher than the fish harvest. This is in line with the Love et al (2015) found that fish production was less profitable than production plant in the aquaponic units analyzed. That may help to explain why we found more than fish production plant production in the current study. Also plant growing cycles are shorter, and the area used for their production tends to be larger than for fish.

Based on the study results of high stocking density ratio in the stagnant water system, the dissolved oxygen concentration decreases due to the increasing metabolism waste. The Duncan Multiple Range Test conducted in each treatment of plant species and stocking density ratio shows the significant differences in the concentration of dissolved oxygen (Table 3).

According to Hepher and Pruginin (1981), this decline of dissolved oxygen and increase of ammonium in the water are caused by the number and size of the cultured fish. Boyd and Linchtkoppler (1982) explained that the higher the stocking density ratio, the higher the demand for oxygen due to the increasing number of fish. Along with the increase in fish weight, the oxygen consumption rate and metabolism waste of each fish also increase. The decrease in the dissolved oxygen concentration may further lead to fish's loss of appetite which stunts the fish growth. Tilapia in farms can tolerate lower concentrations (ranging from 3 to 4 mg/L), the optimum levels of dissolved oxygen are higher, and so the desirable range is usually above 5 mg/L (Pillay 2004), Meanwhile dissolved oxygen that sufficient for the growth of the catfish larvae is above 1 mg/L (Durborow et al. 1985).

Treatment with water plants can heighten the concentration of dissolved oxygen because, in the daytime, the plants are undergoing assimilation and adds oxygen to the water. At night, the plants use the oxygen available in the water for respiration. As a result, the increase of dissolved oxygen concentration due to the treatment with water plants will further improve the appetite of the fish that in turn leads to better fish growth. Dissolved oxygen in water can affect the activity of tilapia and metabolism in the body of the fish (Ardita et al. 2015).

Study results show that nitrate concentration in the culturing media fluctuates from treatment to treatment. The Duncan multiple range test conducted in each treatment of plant species and stocking density ratio shows the significant differences in the concentration of nitrate in the media (Table 4). According to Nelson (2008), nitrate is much less toxic and typically tolerated by most cultured species until it reaches very high levels. Controlling nitrate in aquaponics system is accomplished by the plants.

Water plants ensure the nitrification process runs well due the interaction among fish, water plants and nitrifying bacteria. Protein coming from the feed is decomposed into a simple compound by converter bacteria, such as *Nitrosomonas* that can convert ammonia into nitrite and *Nitrobacter* that converts nitrite into nitrate; this nitrate is further used by the water spinach and lettuce as a nutrient, thus balancing the content of nitrogen in the aquaponics system (Graber and Junge 2009). This is a good thing for us because nitrate happens to be the favorite food of plants. Also the fish will tolerate a much higher level of nitrate than ammonia or nitrite (Blidariu and Grozea 2011). In this condition, the quality of water remains adequate to support fish growth through the good use of feed.

The Duncan multiple range test conducted in each treatment of plant species and stocking density ratio shows the significant differences in the concentration of phosphate in each treatment (Table 5). In the treatment without water plants (control), the phosphate concentration is higher due to its lack of usage in the absence of plants.

According to Effendi (2003) phosphorus in the form of phosphate is a necessary macronutrient and very essential for aquatic organisms including aquatic plants. Lack of phosphate may stunt the growth of phytoplankton which may further affect the aquatic balance in the water (Bahri 2006). At the end of the study, the treatments with water plants result in a lower concentration of phosphate, since the phosphate has been used as a nutrient by plants. On the other hand, in the control treatment without water plants, the phosphate concentration increases due to it not being used by plants. In a low water exchange, the accumulation of phosphate, As and Cu led to higher mortality and reduced larvae length and body weight in the culture of carp (Okemwa 2015). Phosphorus is one of the essential nutrients due compound will be absorbed by phytoplankton and get into the food chain (Hutagalung and Rozak 1997). Orthophosphate is a form of phosphorus that can be directly utilized by aquatic plants, while polyphosphate orthophosphate should be reduced first before being used.

Table 3. Dissolved Oxygen average in each treatment of stocking density ratio and water plant species

Treatment	Lettuce	Water spinach	Control
75 C + 75 N	6.41 b (A)	4.67 b (A)	4.57 a (A)
100 C + 50 N	6.07 b (AB)	6.30 b (AB)	4.57 a (AB)
125 C + 25 N	6.83 b (B)	7.50 b (A)	4.63 a (A)

Note: The means followed by lower cases are not significantly different according to the Duncan multiple range test at 5% degree. The lower cases are read vertically (column) while the upper cases are read horizontally (row).

Table 4. Nitrate concentration average in each treatment of stocking density ratio and water plant species

Treatment	Lettuce	Water spinach	Control
75 C + 75 N	50.00 b (B)	40.00 b (C)	60.00 a (A)
100 C + 50 N	50.00 b (A)	50.00 a (A)	10.00 b (B)
125 C + 25 N	56.67 a (C)	50.00 a (B)	60.00 a (A)

Note: The means followed by lower cases are not significantly different according to the Duncan multiple range test at 5% degree. The lower cases are read vertically (column) while the upper cases are read horizontally (row).

Table 5. Phosphate concentration average in each treatment of stocking density ratio and water plant species

Treatment	Lettuce	Water spinach	Control
75 C + 75 N	3.67 b (A)	4.67 b (A)	5.00 a (A)
100 C + 50 N	3.67 b (A)	4.67 b (A)	5.00 a (A)
125 C + 25 N	4.33 b (A)	3.33 b (A)	5.00 a (A)

Note: The means followed by lower cases are not significantly different according to the Duncan multiple range test at 5% degree. The lower cases are read vertically (column) while the upper cases are read horizontally (row).

Maintain the levels of phosphorus in the aquaponics system is very important because if its levels are too high can cause algae or microorganisms in the water to grow uncontrolled in aquaculture ponds. The deficiency of phosphorus will cause some signs of deficiency include slow growth and leaf stem (Diver 2006).

In conclusion, the productivity of water plants is influenced by the stocking density ratio of fish. The highest water spinach productivity occurs at the stocking density ratio of 75 catfish fry: 75 Nile tilapia fry, at which the average stem length is 59.14 cm, average number of leaves is 13.67, and the harvest weight is 465 g. The highest lettuce productivity occurs at the stocking density ratio of 125 catfish fry: 25 Nile tilapia fry, at which the average stem length is 23.81 cm, average number of leaves is 6.29 and harvest weight is 445.44 g. Growing water plants can improve the quality of water, by increasing the dissolved oxygen concentration and lowering the concentration of nitrate and phosphate, as these substances are used as nutrients by plants. A further study on the polyculture of catfish fry and Nile tilapia fry in an aquaponic recirculating system is required in order to achieve a better water quality that allows for higher stocking density ratios and increased productivity of water plants.

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