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Effects of pH on nitrogen transformations in media-based aquaponics

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HIGHLIGHTS

- Aquaponics could tolerate a wide range of pH from 6.0 to 9.0.
- Higher nitrogen utilization efficiency and N_2O emission were achieved at pH 6.0.
- Denitrification accounted for 75.2–78.5% of N_2O emission from aquaponics.
- Unfavorable conditions for denitrifiers led to higher N_2O emission at pH 6.0.

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ABSTRACT

To investigate the effects of pH on performance and nitrogen transformations in aquaponics, media-based aquaponics operated at pH 6.0, 7.5 and 9.0 were systematically examined and compared in this study. Results showed that nitrogen utilization efficiency (NUE) reached its maximum of 50.9% at pH 6.0, followed by 47.3% at pH 7.5 and 44.7% at pH 9.0. Concentrations of nitrogen compounds (i.e., TAN, NO_2^--N and NO_3^--N) in three pH systems were all under tolerable levels. pH had significant effect on N_2O emission and N_2O conversion ratio decreased from 2.0% to 0.6% when pH increased from 6.0 to 9.0, mainly because acid environment would inhibit denitrifiers and lead to higher N_2O emission. 75.2–78.5% of N_2O emission from aquaponics was attributed to denitrification. In general, aquaponics was suggested to maintain pH at 6.0 for high NUE, and further investigations on N_2O mitigation strategy are needed.

1. Introduction

Aquaculture has become one of the fastest-growing food-producing sectors since 1980s and accounted for almost half (49%) of global fish consumption in 2012 (FAO, 2014). In order to meet the growing human demands for aquatic products, aquaculture scale is bound to continue expand. However, aquaculture is a high-polluting industry. On average, only 25% of its nitrogen and phosphorus inputs could be recovered by target organisms (Crab et al., 2007), and the rest of nutrients are discharged into surrounding water. This is not only a waste of nutrients, but also causes serious pollution to the surrounding environment.

Aquaponics is considered to have potentials to solve the abovementioned problems. Aquaponics is the combination of conventional aquaculture and hydroponics, which could achieve co-culture of fish and plants at the same time. Fish, plants and microbes are three main components of aquaponics, and microbes play the bridge role of converting fish waste to plant nutrients (Somerville et al., 2014). Usually there are three common types of aquaponics designs, i.e., floating raft, nutrient film technology, and media-based bed, mainly classified according to hydroponics (Nelson and Pade, 2007). Of which, media-based bed could act as a filtration unit and provide surface area for microbial growth at the same time. This makes it popular in currently running aquaponics. A survey conducted by Love et al. (2014) discovered that 86% of their respondents adopted media-based aquaponics.

Nitrogen is a vital element for all living organisms. In aquaponics, fish feed that contains high content of protein is added into system and digested by fish. Most of the nitrogen is then excreted in the form of total ammonia (TAN), which is toxic to fish. Fortunately, nitrifying bacteria in aquaponics could first convert ammonia to nitrite (NO_2^-) and then into nitrate (NO_3^-) through nitrification. Nitrate would be reduced to N_2 through denitrification, but more importantly, it is an important fertilizer for plant growth. The establishment of cooperation among three

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Table 1
Performance of aquaponics under different pH treatments.

	Parameters	pH = 6.0	pH = 7.5	pH = 9.0
Phase I	Plant biomass increase (kg/m^2)	2.70[a]	2.48[a]	1.94[b]
	Fish biomass increase (kg/m^3)	0.81[a]	0.87[b]	0.83[a]
	SGR* (%)	0.22	0.24	0.23
	FCR**	3.10	3.02	3.14
Phase II	Plant biomass increase (kg/m^2)	3.01[a]	2.59[b]	2.72[b]
	Fish biomass increase (kg/m^3)	1.31[a]	1.43[b]	1.39[b]
	SGR (%)	0.39	0.37	0.37
	FCR	3.35	3.13	3.22

* SGR (Specific Growth Rate) = (ln Wf − ln Wi) × 100/days, Wf is final weight of fish and Wi is initial weight.
** FCR (Food Conversion Ratio) = total feed given (g) of fish/total wet weight gain (g) of fish.
a,b Different letters show significant differences at $p < 0.05$ (Duncan).

components increases nitrogen utilization efficiency (NUE) and avoids nitrogen-rich wastewater discharge. To achieve higher productivity and better water quality in aquaponics, many kinds of regulation attempts have been conducted. Liang and Chien (2013) found that better fish growth, plant growth, and nutrients removal efficiency from water were obtained in aquaponics under 24-hour light than 12-hour light, and Endut et al. (2010) reported similar results at loading rate of 1.28 m/d. However, thorough study on nitrogen transformations in aquaponics is still lacking.

pH is one of the most important regulation factors for aquaponic systems, and it is needed to be balanced for fish, plants and microbes at the same time. Usually, recommended pH for plant cultivation was slightly acid (5.5–5.8) (Bugbee, 2003), while the optimal pH for nitrification was 7.5–8.0 (Kim et al., 2007). Fish can tolerate a wide pH range, and the optimal pH was different for different species (Arimoro, 2006; Lemarie et al., 2004). In aquaponics, providing the pH optima for every part is impossible, but knowing optimal pH range for the best overall performance is necessary. Tyson et al. (2008) had claimed that reconciling pH for aquaponics should be 7.5–8.0, but no difference in plant yields was detected in their research, which was unreasonable. Essential study is required to investigate the aquaponic performance under different pH conditions. In addition, to achieve the best sustainability, neither yield nor environment impacts could be ignored.

Since biological nitrogen transformations play the key role of bridge in aquaponics, it may cause environmental harms. Nitrous oxide (N_2O), the third biggest greenhouse gas with a global-warming potential 296 times higher than CO_2, is often generated from biological nitrification and denitrification processes. In nitrification, heterotrophic ammonia oxidation bacteria (AOB) could conduct nitrifier denitrification to produce N_2O, and the oxidation of hydroxylamine, intermediate during the oxidation of TAN to NO_2^-, would also lead to N_2O production (Kampschreur et al., 2009). While in denitrification, N_2O which failed to be reduced in time might be emitted to the atmosphere. Previous study has shown that 1.5–1.9% of nitrogen input was lost in the form of N_2O in floating raft aquaponics, while 1.3% was found in conventional aquaculture (Hu et al., 2013, 2015). However, to date, no N_2O emission investigation has been conducted in media-based aquaponics.

In this study, media-based aquaponics was established to investigate the effects of pH on its nitrogen transformations, and special attention was paid to N_2O emission. ^{15}N labeling experiment was used to determine the main source of N_2O emission, and quantitative polymerase chain reaction (Q-PCR) technology was applied to quantify the abundance of nitrifies and denitrifies to reveal the influence of pH on microbial community.

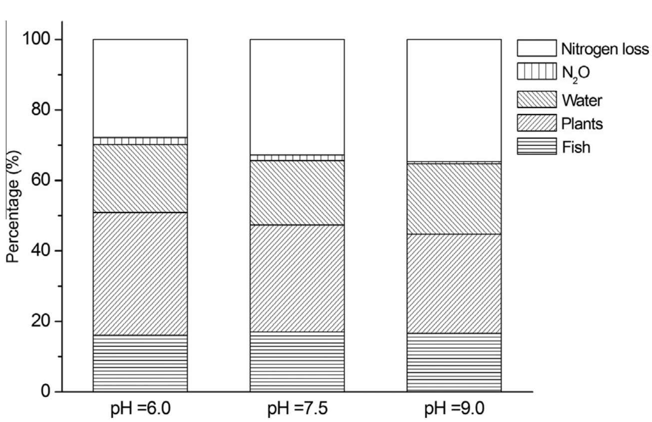

Fig. 1. Nitrogen distribution among different pH treatments.

2. Methods

2.1. Aquaponic microcosms

Experimental aquaponic systems were operated side by side under natural conditions in Jinan, China. A transparent rainproof shed was installed above the aquaponics. All systems shared same setup design. Each system was mainly consisted of two parts, fish tank and hydroponic bed. These two parts were both made of plastic box, i.e., 65 cm × 45 cm × 50 cm for fish tank and 80 cm × 55 cm × 45 cm for hydroponic bed. Fish tank was placed on ground. The effective water volume in fish tank was 100 L. There was no water exchange in fish tank during study period except for water loss through evaporation, transpiration and sampling, which was replenished with freshwater every day. Peristaltic pumps (BT100-2J; Baoding Longer, China) were applied to lift water into hydroponic bed, which was placed above fish tank. Water flow rate was 200 L/d. About 30 cm-deep of perlite with particle size ranging from 1 mm to 3 mm was filled in hydroponic bed. Water from fish tank flowed through hydroponic bed for purification and then purified water flowed back to fish tank under gravity. Air compressors were used to supply air for fish growth and gas flow meters were installed to guarantee that dissolved oxygen (DO) concentration in fish tank was above 5 mg/L.

Common carp (*Cyprinus carpio*) and pakchoi (*Brassica chinensis*), which are very popular aquatic product and vegetable in northern China, were selected to be cultured in this study. Fish with initial weight of 50–70 g was distributed randomly into each fish tank at a stocked density around 10 kg/m^3. Commercial fish feed was used in present study. At the beginning of study, artificial feeding was employed. Fish feed was added into fish tank twice a day, and the unconsumed fish feed was taken out ten minutes later to prevent water from being polluted. From day 31, automatic fish feeders (AF-2005D; Resun, China), which could feed fish four times per day, were introduced into systems. The amount of fish feed was recorded every day. Plant seeds were germinated in seedling-raising plates two weeks before the present experiment began, and then healthy seedlings with similar size were transplanted carefully into hydroponic bed at 20 cm × 20 cm spacing. In order to achieve better plant growth, iron-chelator and hoagland microelement solution were added to supply minerals required for plant growth (Soetan et al., 2010).

A pre-experiment was conducted with present aquaponic systems before study began, in order to accumulate microbes. Present study was carried on for 70 days, and aquaponic systems were operated continuously. Three pH gradients were set as 6.0, 7.5 and 9.0, and each treatment contained three replicates. H_2SO_4 and KOH of 1.0 M were applied to adjust pH every day from the