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Water purification by oyster shell bio-medium in a recirculating aquaponic system

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ABSTRACT

In this study, water purification for cultivating water spinach (WS) or sweet basil (SB) by a recirculating aquaponic system (RAS) was investigated using either an oyster shell (OS) or ceramic ring (CR) bio-medium. Four combinations of OS + WS, OS + SB, CR + WS, and CR + SB were evaluated. The results show that the bio-medium affects both the transfer of NH_3-N to NO_3-N and the biodegradation of organic matter. OS significantly increased the pH and calcium in the effluent. The SEM results revealed that OS has a layer-by-layer structure which supports the growth of a biofilm; the main component $CaCO_3$ of OS released to the solution increases the pH, leading to good nitrification. The total organic carbon (TOC) measurement shows that both bio-media decompose organic matter to smaller than 1 k Da TOC, which provides nutrients that are readily absorbable by the vegetables. Furthermore, the water purification efficiency of RAS is OS + WS > OS + SB > CR + WS > CR + SB.

1. Introduction

In 2015, the record water shortage in Taiwan not only imposed a great challenge to water management but also forced the Taiwanese government to limit the water supply to five days per week. Because Taiwan relies heavily on the rainy season and typhoons for water, the water supply has become less predictable due to global warming. Hence, using water resources intelligently is a viable alternative for meeting the country's increasing water demand.

The wastewater from aquaculture contains a lot of ammonia nitrogen which is toxic to fish. However, the nitrification by bacteria of the bio-medium can transfer ammonia nitrogen to nitrate nitrogen as nutrition of vegetables in the hydroponic culture. Thus, an aquaponic system is an integration of aquaculture with hydroponics and is an excellent way of conserving water because the disposed aquaculture wastewater becomes a fertilizer for the vegetables. Aquaponics is a balanced ecological system among fish, vegetables, and microorganisms in a circulatory process with zero emission of water pollution and low-carbon production. The system has a great potential to effectively solve the crisis of both agriculture and water resources (Graber and Junge, 2009; Emparanza, 2009; Rana et al., 2011; Lam et al., 2013).

Meanwhile, the rapid expansion of mariculture worldwide, due to the depletion of natural marine resources, produces a large quantity of mariculture waste causing great environmental concerns and requires great attention. For example, the oyster shell (OS) waste in Taiwan exceeds 0.16 million tons per year which is primarily either dumped into the coastal water or landfilled (Yen and Li, 2015). In the literature, some researchers reused OS waste as a biofilter for a constructed wetland system or municipal wastewater treatment. In this regard, Liu et al. (2010) investigated OS as an aerated filter medium treatment of municipal wastewater. Park and Polprasert (2008a,b, 2009) evaluated the biodegradation of the nutrients from the wastewater of a school campus by the OS medium. Shin and Chang (2015) utilized OS as the medium of a contact bed to purify the domestic wastewater on a floodway and found that OS performs better than gravel for removing BOD_5 (five days biochemical oxygen demand), T-P (total phosphorous), and NH_3-N. Luo et al. (2013) also studied OS as an active filter for a bio-contact oxidation tank to treat the combined wastewater at an estuary. The average removal efficiencies of COD (chemical oxygen demand), BOD_5, NH_3-N, T-P and TSS (total suspended solids) were 80.05%, 85.02%, 86.59%, 50.58%, and 85.32%, respectively.

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Moreover, Jing et al. (2012) found that coal fly ceramic granules as a biofilter removed 80% of COD (chemical oxygen demand), 85% of NH_4^+-N, and 60% of TN (total nitrogen) from highly polluted river water. Liu et al. (2013) evaluated expanded polystyrene beads for an RAS; 85% of the TAN (total ammonia nitrogen) could be removed. Graber and Junge (2009) found that 69% removal of TN (total nitrogen) could be achieved by using a light-expanded clay aggregate in their RAS. Tyson et al. (2007) observed that nitrification by a perlite medium was better at a pH of 8.5 than at a pH of 6.5. Similarly, plant roots also uptake nitrogen (Liu et al., 2015; Zhang et al., 2014; Zhou et al., 2011) and have a good water purification function as examined by Li et al. (2009) and Endut et al. (2009, 2010). They assessed a bio-filter mat formed from the plant roots of a hydroponic system. The removals of nitrogen and phosphorus were 62.2% and 75.9%, respectively.

To date, no studies have employed OS as a bio-medium for the RAS. As the bio-medium plays a key role in maintaining a high amount of active biomass and a variety of microbe populations, this study was specifically aimed at this aspect of water purification for the RAS. The water treatment efficiencies by OS and commercial CR (ceramic ring) bio-media, including BOD_5, TOC (total organic carbon), NH_3-N, NO_3-N, and PO_4-P and the molecular weight distribution were evaluated. Furthermore, the structure, component, and nutrient removal mechanisms of OS and CR were investigated. The nutrient removal of water spinach (WS) and sweet basil (SB) by the hydroponic system was evaluated as well for comparison.

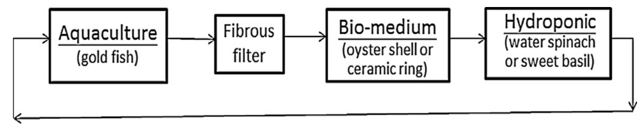

Fig. 1. Experimental setup of the recirculating aquaponic system.

2. Material and methods

2.1. Recirculating aquaponic system (RAS)

The RAS was established outdoors for cultivation with natural sunlight in a net-house as shown in Fig. 1. It comprised an aquaculture trough, fibrous filter, bio-medium, and hydroponics in sequence. The volume of aquaculture trough was 19 L in which 15 L tap water was infused for cultivating goldfish (Carassius auratus) of 5 g fish/L at the beginning. The fish were fed twice daily with a pellet diet containing 40% protein in the amount of 0.3 g food/g-fish-day. The DO (dissolved oxygen) of the water in the trough was maintained at 7.2 ± 0.2 mg/L by an air diffuser. The amount of water in the trough was maintained at 15 L by adding the needed quantity of tap water daily. The effluent from the aquaculture trough was filtered by a fibrous filter to remove solid wastes; the filter was

Fig. 2. The bio-media (left: OS; right: CR).

Fig. 3. Hydroponic vegetables (left: WS; right: SB).