InnoFish - innovative adaptation of integrated aquaculture in an established extensive fish farm

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Abstract. Aquaculture has been the fastest growing sector in food production for multiple decades and is expected to resume this trend for the foreseeable future. However, its continuous growth led to increasing issues concerning wastewater treatment, energy management and environmental friendliness. To improve wastewater treatment in established aquaculture flow-through systems, a preliminary trial was conducted testing the potential effects of a biofilter with an integrated vermiculture and a hydroponic unit on the ammonium, nitrite and nitrate concentration in the effluent water from a traditional trout farm. This cost-effective filter system was able to reduce ammonium-waste in the effluent. Observations suggest that the biofilter was the main factor behind this reduction. Although the nature of this preliminary study could not conclusively clarify all factors involved in this wastewater treatment method, it could demonstrate the great potential of this cost-effective system in classical aquaculture facilities. This short communication will discuss the potential benefit of innovative adaption of integrated aquaculture in established fish farms, its limitations and further research needs.
Key Words: ammonium, aquaponics, biofilter, nitrate pollution, vermiculture.

Introduction. Since the 1950's global aquaculture production increased from 20 million to around 80 million tons in 2016 (FAO 2020). However, most wastewaters are still being introduced into nearby water systems, which led to raising attention concerning negative impacts from aquaculture on the environment (Subasinghe et al 2009; Bureau & Hua 2010). Nitrate is one of the most common pollutants in groundwaters (Menció et al 2016). Most nitrate originates from agriculture, including aquaculture (Knoll et al 2020), where biological filtration is mostly not intended (BLE 2017). A commonly known practice in recirculating aquaculture systems (RAS) is the use of bacterial nitrification in biological filters to reduce ammonium concentration which originated from nitrogen excretion of farmed fish. To subsequently decrease nitrate in wastewater, integration of a hydroponic unit in RAS can be applied (Wongkiew et al 2017). This method of additional wastewater treatment in aquaculture is known as aquaponics, which combines further recycling of waste with the farming of ornamental plants or other valuable crops (Wongkiew et al 2017). Due to the effective recycling of water, RAS systems are being promoted in many different countries of the European Union to increase sustainability of aquaculture (Badiola et al 2012). Additional integration of species into a RAS to further exploit the nutrients assimilating in aquaculture farms is also referred to as integrated multitrophic aquaculture (IMTA). Latter approach usually combines fed aquaculture (finfish) with extractive aquaculture (organic extraction via shellfish or worms and inorganic extraction via plants) to effectively use the available nutrients (Chopin et al 2010). The IMTA approach has also been applied in freshwater ponds to improve water quality (Kibria & Haque 2018).

In Germany, aquaculture mostly consists of ponds and open flow through-systems, where processed water is often simply discharged into natural environments. During this preliminary study, the potential effects of the integration of a biological filter including a vermiculture as well as a hydroponic unit into the effluent water stream of a commercial trout farm were examined. This IMTA approach to an established flow-through system was expected to reduce the pollution with nitrogen compounds (ammonium, nitrite and nitrate) to the environment. First insights will be shared in this article as well as potential benefits, concerns and further research needs.

Material and Method

Experimental design. The biofilter including the vermiculture consisted of a 1 m^3 IBC-container and 700 L of biocarrier Hel-X-Flake (Stöhr GmbH & Co. KG, Marktrodach, Germany) and was coupled to the drain (1.5 L s^{-1}) of the flow-through system stocked with trout (*Oncorhynchus mykiss*) (Fisheries Bauer Detlev, Speichersdorf, Germany). The integrated vermiculture consisted of 1 kg *Eisenia hortensis* (Michaelsen, 1890) which were placed on the biocarrier. A baffle plate was placed in the center of the biofilter to evenly distribute the inflowing water. The drain of the biofilter was connected to the hydroponics system. Latter consisted of a 3000 L tank and 10 plants of water mint (*Mentha aquatica* Linnaeus, 1753). The biofilter was isolated with expanded polystyrene during winter months to achieve a more consistent temperature regime. Ammonium (Ammonium Küvetten-Test, Hach Lange GmbH, Düsseldorf, Germany), nitrite (Nitrit Küvetten-Test, Hach Lange GmbH, Düsseldorf, Germany), nitrate (Nitrat Küvetten-Test, Hach Lange GmbH, Düsseldorf, Germany), temperature (HQ40D Portables 2-Kanal Multimeter, Hach Lange GmbH, Düsseldorf, Germany), pH (HQ40D Portables 2-Kanal Multimeter, Hach Lange GmbH, Düsseldorf, Germany) and conductivity (HQ40D Portables 2-Kanal Multimeter, Hach Lange GmbH, Düsseldorf, Germany) were measured biweekly. The experiment started in July 2019 and ended in September 2020. Worms were not additionally fed.

Results and Discussion

Preliminary results. Average water temperature measured during the experimental period was 8.95±5.81°C, pH was 7.21±0.55 and conductivity 271.90±116.54 µS cm^{-1}. The average influent concentration of ammonium from the trout pond to the biofilter was 0.569±0.795 mg L^{-1} while the effluent concentration was 0.278±0.427 mg L^{-1}. This was on average a reduction of 50.26%. The highest reduction of ammonium measured at a single sampling event was 95.70%. The concentration of ammonium in the effluent water of the hydroponic unit was 0.245±0.340 mg L^{-1}. The average influent concentration of nitrite from the trout pond to the biofilter was 0.037±0.021 mg L^{-1} while the effluent was 0.032±0.024 mg L^{-1}. This equated to an average reduction of 13.51%. The concentration of nitrite in the effluent of the hydroponic unit was 0.034±0.026 mg L^{-1}. The nitrate concentration in the pond effluent was 3.081±0.768 mg L^{-1} while biofilter effluent water had an average nitrate concentration of 3.030±0.733 mg L^{-1}. This was an average reduction of 1.7%. The concentration of nitrate was 2.962±1.036 mg L^{-1} in the effluent of the hydroponics tank. During the experimental period, total weight of mint increased from 0.5 to 16 kg.

Potential benefits. Preliminary results showed the promising potential of the inclusion of a biofilter, a vermiculture and a hydroponic unit into the wastewater stream of a commercial flow-through trout farm. Depending on different factors, this cost effective IMTA approach to classical trout farms could be able to noticeably reduce pollution of the environment with nitrogen compounds like ammonia. This method could drastically decrease the impact existing fish farms - which do not contain a water treatment system - have on the environment. The system was installed in a simple manner and acquisition costs were minimal. Furthermore, both worms and mint can be marketed at appreciable prizes to create an additional income for fish farmers. However, the effectiveness of this water treatment system is dependent on multiple factors including temperature, pH, conductivity, nutrient availability, oxygen concentration, accumulation of organic matter and others.

Potential concerns and future research needs. Epigeic worms including *E. hortensis* favor temperatures between 20 and 25°C (Wilson et al 2014; Domínguez 2018).

Vermicomposting can be an effective method for reducing organic waste, however, large variations in temperature will not be tolerated by epigeic worms (Manyuchi et al 2012; Domínguez 2018). Therefore, vermiculture most likely did not contribute significantly to the treatment of wastewater during this experiment. The effective inclusion of worms to a system that is constantly exposed to environmentally induced temperature changes should be further investigated. Other species of worms might be more suitable. Similarly, nitrification is temperature dependent, in which bacterial growth is already inhibited by approximately 80% at a temperature of 10°C (Stark 1996). The loss of ammonia in the biofilter could therefore, at least during colder months, be explained by growth of microalgae on the biocarrier. Microalgae prefer ammonia over nitrate for assimilation into amino acids (Dortch 1990). This process could also explain the lack of an increase in nitrite and/or nitrate concentration following a reduction in ammonia, as neither nitrite nor nitrate are released from microalgae during this process (Chen et al 2012). These mechanisms and the resulting potential for water treatment systems should be further investigated in future studies. According to observations by Melzer & Kaiser (1986) content of water mint increases during winter months, which indicates that nitrate uptake is not inhibited at low temperatures. However, there was no appreciable nitrate reduction observed for most of the experimental duration. Plants with low biomass in running waters are likely not able to remove significant amounts of nitrate from the surrounding water (Howard-Williams et al 1982) and the biomass of the water mint might have been insufficient for a noticeable nitrate uptake. Other factors besides temperature might have been responsible for non-optimal growth of water mint. Furthermore, the nitrate uptake rate is also dependent on factors like nutrient concentrations, light intensity, humidity and ambient carbon dioxide concentration (Wongkiew et al 2017), which should be considered and examined in future experiments.

A pH range of 5.0 to 9.0 was suggested to be optimal for worm growth (Singh et al 2005). Hence, pH was in a suitable range for vermiculture during the experimental period. However, while the pH was in the operational range for trickling filters (6-9; Tyson et al 2004; Eding et al 2006), pH was not optimal for plant growth (5.5-6.5; Tyson et al 2004; Caló 2011). The comparably high pH of the effluent water therefore probably limited plant growth to some extent, which could also have limited their ability to absorb nitrate, as a greater plant biomass is able to absorb larger amounts of this nitrogen compound (Howard-Williams et al 1982) and nutrient absorption capacity can be limited at non-optimal pH (Karimaei et al 2001; Rakocy et al 2004). If the reduction in pH by the biofilter is not sufficient for optimal plant growth, an additional reduction in pH prior to the hydroponic unit could be suitable to optimize nitrate elimination.

Electrical conductivity has been reported to be optimal in a range between 0.8 and 4 $\mu S\ cm^{-1}$ in hydroponic systems (Singh & Dunn 2016; Homoki et al 2020). The conductivity measured in the effluent water of the trout farm could therefore have been non-optimal for plant growth. This represents an additional issue for nitrate elimination in the hydroponic unit which should be addressed in future research.

Another factor influencing plant growth and therefore nitrate uptake in an aquaponic system is the availability of certain essential nutrients like calcium, potassium and iron (Rakocy 2007). All of which are usually supplied in sub-optimal quantities when fish feed is the basic source of nutrients (Rakocy 2007). Since this water treatment method combined with the trout farm essentially represents an aquaponic system (coupled with vermiculture), availability of these nutrients was probably limited and could be optimized in future experiments. Vermiculture can increase nutrient availability for plants from waste sediments (Kasozi et al 2021) and an optimized vermiculture could address this issue.

Furthermore, adequate levels of dissolved oxygen are required for both bacteria and plants (Rakocy 2007). Dissolved oxygen concentration in outlets of trout farms can be at a suitable level for biofilters due to aeration of fishponds (Boaventura et al 1997), however, oxygen consumption of biofilters can be high (Colt et al 2006), which reduces oxygen concentration for connected hydroponic. Dissolved oxygen levels should be above 5 $mg\ L^{-1}$ around plant roots to ensure optimal growth (Rakocy 2007). This should be accounted for in future experiments. The adequate supply of plant roots with oxygen could additionally be impaired by accumulating solids, which reduce oxygen levels via their decay (Rakocy 2007). Excess solids will also adhere to plant roots, disturbing water and nutrient uptake (Nelson & Pade 2007; Rakocy 2007). Vermicultures are able to reduce levels of solids (Manyuchi et al 2012) and this effect should be further investigated concerning its adequate removal of solids in the filter system described in this article.

Conclusions. This preliminary study was able to demonstrate the potential benefits that an IMTA approach to a classical flow through system could have for the environment. However, further research is needed to improve this system to fit the specific factors present in established flow-through or pond systems.

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Conflict of interest. The authors declare that there is no conflict of interest.

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