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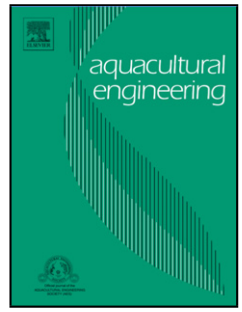

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Model-based management strategy for resource efficient design and operation of an aquaponic system

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Abstract

Aquaponics is a technique that combines *aqua*culture with hydro*ponics*, i.e. growing aquatic species and soilles plants in a single system. Commercial aquaponics is still in development. The main challenge consists in balancing the conditions required for the growth of multiple species, leading to dynamic a system with high complexity. Mathematical models improve our understanding of the complex dynamics in aquaponics, and thus support the development of efficient systems.

We developed a water and nutrient management strategy for the production of Nile tilapia (*Oreochromis niloticus*) and tomato (*Solanum lycopersicum*) in an existing INAPRO aquaponic demonstration system in Abtshagen, Germany. This management strategy aims for improved water and nutrient efficiency. For this purpose, we developed a system-level mathematical model and simulation.

In our simulations, we found that the existing configuration and water management of the Abtshagen aquaponic system results in an excessive amount of water discharged from the RAS. Therefore, sending more nutrient-rich water from fish to plants can help reducing water and fertilizer consumption. However, this water transfer may lead to excess concentrations of some nutrients, which could stress fish, plants or both. For the Abtshagen system, our simulations predicted excess concentrations of total suspended solids (TSS) for the fish, and sodium (Na^+) and ammonium nitrogen (NH_4^+-N) for the plants. Furthermore, our simulations predicted excess calcium (Ca^{2+}) and magnesium (Mg^{2+}) for plants, due to the use of local fresh water with relatively high concentrations of those ions.

Based on our simulations, we developed an improved management strategy that achieves a balance between resource efficiency and water quality conditions. This management strategy prevents excess levels of TSS for fish, and Na^+ and NH_4^+-N for plants. Under the improved management strategy, simulated water requirements (263 $L/kg\ fish$ and 22 $L/kg\ tomato$) were similar to current commercial RAS and greenhouse horticulture. Simulated fertilizer requirements for plants of N, Ca and Mg (52, 46 and 9 $mg/kg\ tomato$, respectively) were one order of magnitude lower than in high efficient commercial closed greenhouse production.

Keywords: aquaponics, mathematical model, resource efficiency

1. Introduction

Land-based aquaculture can help increasing local fish production, and its development has led to systems with low water consumption. Intensive recirculating aquaculture systems in the Netherlands can require less than 1 $m^3\ water/kg\ fish$, competing with livestock levels. Recirculating aquaculture production is increasing worldwide, but operational requirements like energy and water purification are still a challenge resulting in high investment costs [1]. High cost for water purification is due in part to the accumulation of excess nutrients. Hydroponic horticulture has been suggested and tested to utilise excess nutrients from aquaculture [2]. In the Netherlands, greenhouse horticulture is very well developed, but it depends on external fertilizer. Therefore, the current technological status of aquaculture and greenhouse horticulture represents an opportunity to balance their mutual needs.

Aquaponics is a production technique that combines aquaculture with hydroponics. This combination has been long known: as rice fields combined with fish culture in South-East Asia [3], and as *chinampas* by the Aztecs [4]. Researchers of recirculating aquaculture introduced the modern concept of aquaponics in the mid-1970's as a combination of intensive production systems (with low land and water use); but commercially competitive aquaponics is yet to be achieved [5]. The main challenge lies in balancing the water quality and the nutrients required by three

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