LEIBNIZ-WISSENSCHAFTSCAMPUS PHOSPHORFORSCHUNG ROSTOCK

Final Report

Nutrient fluxes in commercial African catfish (*Clarias gariepinus* Burchell) recirculating aquaculture systems (RAS): Implications for aquaponics

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Content

* Liste der: Forschungsaufenthalte außerhalb der betreuenden Einrichtungen, Vorträge bzw. Poster auf Konferenzen, Öffentlichkeitsarbeit und/oder Publikationen

1 Summary and conclusions:

The production of African catfish (*Clarias gariepinus*) is becoming increasingly important in Germany, where it is produced exclusively in recirculating aquaculture systems (RAS). Due to the natural accumulation of plant-relevant nutrients in the process water of such RAS and a high tolerance of the African catfish towards reduced water quality, this combination offers a high potential for an economical aquaponic application in Germany. As a part of this dissertation, the term aquaponics was newly defined. Subsequently, the properties of the rearing water of African catfish RAS for subsequent use in commercial aquaponics were assessed under different production intensities – extensive, semi-intensive and intensive. Finally, the ability of the African catfish to cope with elevated levels of ortho-phosphate (ortho-P) originating from specific fertilizers to increase plant growth in hydroponics was assessed.

This dissertation demonstrates that under commercial conditions, African catfish RAS can be used to supply plant production sufficiently with nutrients, to comply with the definition of aquaponics in the sense of Palm et al. (2018a). Due to suboptimal nutrient concentrations, relatively low fish production and high labor costs, the semi-intensive production cannot be recommended due to a negative total cost benefit balance. Extensive and intensive production is possible and can be adjusted with different aquaculture species to meet the local market demand. Nutrient supplementation (i.e. ortho-P) can be performed up to levels that favor optimal growth of plants.

2 Introduction and goals of the dissertation:

Integrated agricultural production systems are becoming increasingly important in research and development to increase the sustainability in food production. An example of such integrated systems of production is aquaponics. The combined production of fish and plants follows the aquaponics principle, sharing nutrients from the same process water. The combination of fish and plant cultivation in coupled aquaponics dates back to the first system designed by Naegel (1977) in Germany, represented by a 2000-L-sized system at the hobby installation scale in a controlled-environment greenhouse. This system was developed to verify the use of nutrients from fish waste-water under fully controlled recirculating water conditions for plant production, extending the already developed use of nutrients from industrial and domestic wastes for plant and animal production towards aquatic organisms. The author based his concept on an open pond aquaponic system at the South Carolina Agricultural Experiment Station, USA, where excess nutrients from fish ponds stocked with channel catfish (*Ictalurus punctatus*) were eliminated by means of hydroponic production of water chestnut (*Eleocharis dulcis*, Loyacano and Grosvenor, 1973). Establishing nitrification and denitrification tanks to increase the nitrate concentration inside his system, Naegel (1977) attempted a complete oxidation of all nitrogenous compounds, reaching nitrate concentrations of 1200 mg NO_3 L^{-1}, and demonstrating the effectiveness of the nitrification step. Though he only stocked his system with a low density of 20 kg m^{-3} tilapia (*Tilapia mossambica*) and carp (*Cyprinus carpio*), the tomatoes (*Solanum lycopersicum*) and iceberg lettuce (*Lactuca sativa*) grew well and produced harvestable crops. These first research results led to the concept of coupled aquaponic systems, in which the plants uptake the nutrients provided from the fish, causing adequate growth and highly efficient water use in both units.

Problem formulation 1: Due to the variety of constructions that follow the aquaponics principle and many different names for these production systems inside the literature, they so far cannot be delimited due to the lack of comprehensive definitions. The **first goal** of this project and dissertation by Strauch (2018) was to define the term aquaponics allowing further research but also industrial developments.

Problem formulation 2: Due to the fact that the nutrient availability and composition in commercial African catfish recirculating aquaculture systems was relatively unclear, the **second goal** of this project was a better understanding of the nutrient fluxes in commercial African catfish RAS, evaluating the subsequent usability of the process water for commercial aquaponics.

Problem formulation 3: Nutrients, including phosphate, do not only accumulate in fish fillet (human consumption) and process waters (aquaponics) but also in the fish carcass and solid wastes. Because no information was available that provides detailed and comparable data as a basis for system modeling, but also to get first insights into possible recycling options for aquaculture by-products (sediments), the **third goal** of this project and dissertation was to assess the general nutrients, phosphate - and other (toxic) - element pathways in African catfish RAS.

Problem formulation 4: African catfish RAS expose the animal to relatively high levels of dissolved nutrients. Less available inside the process water is phosphate (**see problem 3**) that is required to provide optimal plant growth. Consequently, in coupled aquaponics, nutrient availability to the plants must be improved. The levels of ortho-phosphate (ortho-P) may increase as a consequence of nutrient management in the plant units. So far there is no evidence if the application of ortho-P in African catfish aquaponics can impair fish performance, welfare indicators or product quality. The **fourth goal** of this project and dissertation was therefore a better understanding of the influence of dissolved ortho-phosphate onto African catfish, allowing an increase to optimal ortho-P levels inside the hydroponics in order to achieve better plant growth.

3 Materials and methods

The most important publications dealing with the research topic aquaponics were analysed and categorized. A main result of the dissertation was a new nomenclature that comprehensively defines the term ‘aquaponics’ and its concept, delimiting it from other integrated aquaculture concepts not covered by this term.

To get an overview of the nutritional properties of the process waters of practice-relevant aquaculture facilities, three semi-commercial recirculating aquaculture systems were stocked with African catfish (*Clarias gariepinus*) at three different stocking densities (“extensive“: 35 fish, max. 50 kg fish tank^{-1}; “semi-intensive“: 70 fish, max. 100 kg fish tank^{-1}; “intensive“: 140 fish, max. 200 kg fish tank^{-1}). The fish was fattened under five different management regimes, respectively. The assessment involved a “run-in”-phase, a “batch”-phase, and three “staggered” production phases, which differed in the age of the biofilters, the water-reuse rate, and feed input. Relevant production parameters, i.e. stocking density, feed input, water use, and the resulting water quality parameters, e.g. dissolved oxygen, pH, electrical conductivity and the concentrations of primary macro-nutrients were analyzed and budgeted.

With regard to the reuse of energy and nutrients, especially phosphate, in the various by-products of the aquaculture of African catfish, the biologically relevant in- and output material flows of the RAS were examined and budgeted under three different production intensities and two different levels of feed input, respectively. Fresh water and feed were considered in the entries, whereas both were assessed for animal- and plant relevant macro- and micro-nutrients and pollutant elements, as well as the calorific value of the feed. The outputs were accounted for the fish (carcass, fillet), process water and solid effluents that accumulated in the clarifiers, all of which included animal and plant relevant macro- and micro-nutrients, elemental pollutants, and in addition, the calorific values in the fish (carcass, filet) and deposited solid wastes in the clarifiers.

In order to assess the tolerance of plant-available ortho-P on growth, welfare, and in the broadest sense, alternative uptake mechanisms in African catfish, an experiment investigated how elevated levels of ortho-P inside the process water affected the essential growth and welfare parameters. The concentrations of ortho-P were aimed at four levels, with group 1 (control: P0, without addition of fertilizer): ortho-P > 0 - < 10 mg L^{-1}, group 2 (P40): 40 mg L^{-1}, group 3 (P80): 80 mg L^{-1}, and group 4 (P120): 120 mg L^{-1}.

4 Results

An essential result of this project, published as a part of the dissertation by Strauch (2018) and inside the peer reviewed literature, is a new definition of the term aquaponics including a comprehensive nomenclature for the different aquaponic systems, delimiting them from each other as well as from other forms of integrated aquaculture systems.

Despite a staggered production scheme and consistent compliance with characteristic maintenance protocols, the nature of the process water in terms of the physico-chemical parameters and nutrients availability was unstable. As a consequence of the rapid growth of the fish and the required system management, the physico-chemical water parameters (dissolved oxygen, pH, conductivity) but also the concentrations of dissolved nutrients (N, P, K, Ca, Mg) were variable over the production period.

The analyses of the mass balance revealed that the input nutrients (via feed and tap water) accumulated very differently along with the output pathways (process water, settled solids, fish carcass and fillets). Most P (≈90%) accumulated in the fish carcass, most micro-nutrients in the settled solids. While most of the input P was recorded, appr. 40% per input N was unaccounted for.

It could be demonstrated that the growth and feed efficiency of African catfish inside an experimental setup by trend were best at plant relevant concentrations of 40 and 80 mg L^{-1}, with no negative consequences on animal welfare. While the activity of the fish reduced with an increase in levels of ortho-P inside the process water, the number of biting wounds increased in the group P120.

5 Discussion and conclusions

We found that an update of the definition of the term ‘aquaponics’ and the development of a comprehensive nomenclature allows distinguishing all so far known forms of aquaponics from other integrated production systems combining fish and plants, such as ‘Integrated Multi Trophic Aquaculture’ or ‘Fish Rice Culture’. Referring to clear principles, this new definition and nomenclature allows initiation of future public and private research and investment, at both the home and also the industrial scale.

Given that the water quality parameters varied notably over time, the usability of African catfish RAS process waters for subsequent use in aquaponics is impaired. Low nutrient concentrations in the RAS process waters require adequate system management allowing the target amount of 50% of the nutrients required for optimal plant growth derived from the fish wastes alone. Increase in production intensity can shift the levels of plant available ortho-P to nearly adequate levels required for optimum plant growth.

The largest output of energy and nutrient enriched by- and waste-products was found in the carcass, which is why this by-product has the greatest potential in a circular agricultural economy. Furthermore, there are also substantial amounts of nutrients inside the process water and the solid effluents, which could also be used in terms of a circular economy, whereas reuse in aquaponics is superficial. In principle, it could be demonstrated that the elements are distributed differently with regard to the output pathways.

Given that the nutrient profile of the process water from African catfish RAS does not match the recommendations for hydroponically produced plants, its solely use as hydroponic nutrient solution is unlikely to provide the optimal nutrient requirements for the plants. Consequently, productivity and quality of the plant produce is most likely to be impaired for many plants. In order to utilize the dissolved nutrients from African catfish RAS in hydroponics, targeted nutrient adjustment is required to optimize the nutrient profile. Growth trials with different plants are required to test the influence of specific nutrients, e. g. P, Fe, Mo, Mn, K, etc., on the productivity and quality of the different plants.

The high concentration of plant essential nutrients (P, and most micro-nutrients) contained in the solid effluents from RAS are a potential source for plant nutrition. In order to utilize these nutrients in aquaponics s.s. according to Palm et al. (2018a), easy to use mineralization technologies must be tested.

Economical, ecological and ethical considerations require healthy animals with high feed efficiency in aquaculture production. Modern integrated systems such as aquaponics demand adjustment of water parameters in order to improve plant production, however, with no negative consequences onto fish growth, welfare and product quality. We could demonstrate that elevated levels of ortho-P up to 80 mg L^{-1} inside the rearing water of African catfish do not negatively affect the fish, while 120 mg ortho-P L^{-1} significantly reduces the welfare status. This allows limited addition of ortho-P fertilizer to the plant units even in coupled aquaponics with African catfish and the reuse of the plant water in the catfish recirculation aquaculture system.

6 References

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Naegel, L.C.A. 1977. Combined production of fish and plants in recirculating water. Aquaculture 10, 17–24.

Appendix

Workshops and certificates:

- COST Action FA1305 Training School: 'Microbial Roles and Dynamics in Aquaponics', University of Liège, Gembloux Agro-Bio Tech Faculty, Belgium, 25–28 April 2016
- COST Action FA1305 Working Group meetings, University of Murcia, Murcia, Spain, 18–20 April 2017
- COST Action FA1305 Training School: 'Aquaponics: Ergonomics and Economics", AquaBio Tech, Mosta, Malta, 30 October–2 November

International presentations:

- Les Rendez-vous de Concarneau: where Industry meets Science » 2016, 29–30 September 2016, Marine Station of Concarneau , Concarneau, France: Strauch, S.M., Knaus, U., Palm. H.W. 'Aquaponics–the German Experience'
- COST Action FA1305 Working Group meetings, University of Murcia, Murcia, Spain, 18–20 April 2017: Strauch, S.M., Knaus, U., Wasenitz, B. Bischoff-Lang, A.A., Palm, H.W. 'Nutrient dynamics in aquaponics of African catfish (*Clarias gariepinus*) and Moroccan mint (*Mentha spicata*)'
- EAS Aquaculture Europe 2016, 20–23 September 2016, Edingburgh, Schotland: Strauch, S.M. Palm, H.W., Knaus, U., Bischoff-Lang, A.A. 'Proportional up-scaling of African catfish (*Clarias gariepinus*) recirculating aquaculture systems disproportionally affects nutrient dynamics'
- WAS/EAS AQUA 2018, 25–29 August 2018, Montpellier, France: Strauch, S.M., Bischoff-Lang, A.A., Bahr, J., Baßmann, B., Oster, M., Wasenitz, B., Palm, H.W. 2018. 'Effects of ortho-phosphate in the rearing water of juvenile African catfish on (*Clarias gariepinus*) on welfare, growth and product quality.
- COST Action FA1305 Final Conference, 'Aquaponics: From Science to Practice', University of Greenwich, London, UK, 09–10 April 2018: ' Commercial African catfish (*Clarias gariepinus*) recirculating aquaculture systems (RAS): assessment of element and energy pathways with special focus on the phosphorus cycle

Publications:

Palm, H.W., Knaus, U., Appelbaum, S., Goddek, S., Strauch, S.M., Vermeulen, T., Jijakli, H.M., Kotzen, B. 2018a. Towards commercial aquaponics: a review of systems, designs, scales and nomenclature. Aquac. Int. 1–30.

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Strauch, S.M., Wenzel, L.C., Bischoff, A., Dellwig, O., Klein, J., Schüch, A., Wasenitz, B., Palm, H.W. 2018. Commercial African catfish (*Clarias gariepinus*) recirculating aquaculture systems:

assessment of element and energy pathways with special focus on the phosphorus cycle. Sustainability 10, 1–29.

Strauch, S.M., Bahr, J., Baßmann, B., Bischoff, A.A., Oster, M., Wasenitz, B., Palm, H.W. 2019. Effects of ortho-phosphate on growth performance, welfare and product quality of juvenile African catfish (*Clarias gariepinus*). Fishes, 4, 20.