Final Report

Title: Sustainable and cost-effective aquaculture waste-sludge reutilization system based on optimum nutrient management in integrated multitrophic aquaculture and horticulture systems

Report

The NRAC-funded research conducted at the University of New Hampshire for the project titled "Sustainable and cost-effective aquaculture waste-sludge reutilization system based on optimum nutrient management in integrated multitrophic aquaculture and horticulture systems" began in January 2019 after significant delays in funds availability. As this research was conducted in parallel with other federally-funded projects, the objectives were quickly addressed once funding was secured. The following objectives were the basis of the NRAC research: (i) determine the viability for aquaponic production of spinach and lettuce in the Northeast using the nutrients from the waste-sludge of a recirculating aquaculture system (RAS); (ii) identify, quantify, and evaluate plant-available nutrients in a RAS to develop a hydroponic nutrient solution; (iii) investigate root zone nitrification as a way to reduce capital costs by eliminating traditional biofilters; (iv) build an economic model to analyze options for local growers; (v) validate findings in a commercial context and develop standardized system designs; and (vi) develop and implement industry workshops for direct technology transfer.

Objectives ii, iv, and vi were addressed in the first year of research, and results are pending as a result of graduate student studies hampered by the COVID-19 required University and research facility shutdowns. Additionally, a change in the Dr. Timmons's status at Cornell University, and Dr. Guerdat's departure from UNH caused additional setbacks in completing the research. Below is a summary of the work completed to date. All theses from the graduate students participating in the NRAC research will be publicly available once accepted by the UNH University Graduate Program.

The target audiences for this research included the public, education, Extension, and small farmers. All audiences were engaged in the system design and research information dissemination via workshops, conference presentations, and in-person facility tours and trainings. During the early stages of this reporting period, standardization of the replicated farm-scale research facilities was coordinated. Once standardized, intensive study was conducted on the operational inputs and outputs as part of five MS graduate students, one team of 5 undergraduate environmental engineering students, and one undergraduate business administration student. Collaborators from UNH and Cornell University were engaged in system operational parameters for practical applicability of research. During this reporting period, numerous facility tours were provided to the public, Extension professionals, members of the press/media, high school students, university students, and university administrators. However, in March 2020 the research facilities were depopulated and shut down due to the restrictions for in-person work as a result of the COVID-19 pandemic.

Two aquaponics workshops were delivered during the reporting period. In June 2019 a 3-day hands-on, experiential workshop was hosted at the UNH Kingman Farm Aquaponic Research Greenhouses. Workshop participants included members from private industry (manufacturing, production, controlled environment agriculture), academic (high school, undergraduate, and graduate students), and policy and outreach (Extension, FDA, USDA). The

26 participants learned about all aspects of aquaculture, hydroponics, nutrient management, and environmental control through lectures and presentations delivered by project participants and collaborators. Each day of the workshop included hands-on training opportunities in the facilities, and the last day offered an opportunity for participants to tour regional aquaponic and greenhouse production facilities as an opportunity to see the opportunities for the application of the research outcomes. In February 2020, the Aquaponics Principles and Practices Workshop was delivered in the days prior to the Aquaculture America conference. Similarly, research results and system design principles were taught to participants. In the UNH academic spring semester (January-May 2020), the combined undergraduate and graduate-level Aquaponics course (SAFS 740 / ANFS 840) was offered for a second time. This course had 16 enrollees (14 undergraduate, 2 graduate) and provided lecture-based education and hands-on experience working in the research facilities. In the previous reporting period, a group of five senior Environmental Engineering students conducted a preliminary comprehensive analysis of the facilities measuring water, nitrogen, and energy consumption and developed an MS Excel-based spreadsheet model. In this reporting period the model was checked, validated, and optimized to deliver outputs for researchers, growers, and Extension professionals in estimating nutrient, water, and energy consumption requirements for facilities of different size/scale.

Products/Presentations

Guerdat, T., Fogarty, S., 2019. Addressing Food Safety in Aquaponics Through System Design. Annual FDA Food Safety meeting hosted by the New Hampshire Health and Human Services Department. Portsmouth, NH. September 2019.

Guerdat, T., Sitek, A., Konjoian, P., Berlinsky, D., 2020. Characterizing nutrient production from rainbow trout and tilapia growout in recirculating aquaculture systems for potential use in hydroponic crop production. Aquaculture America conference, World Aquaculture Society. Honolulu, HI. February 2020.

Guerdat, T., Fogarty, S., Jones, S., Konjoian, P., 2020. Microbial water quality and food safety in recirculating aquaponics. Aquaculture America conference, World Aquaculture Society. Honolulu, HI. February 2020.

Guerdat, T., DeVitto, A., Poleatewich, A., Mattson, N., Konjoian, P., 2020. Optimizing aquaponic strawberry production in the Northeast for year-round production. Aquaculture America conference, World Aquaculture Society. Honolulu, HI. February 2020.

Guerdat, T., Tetreault, J., Mouser, P., Timmons, M., 2020. Optimizing microbial digestion and nutrient solubilization of rainbow trout and tilapia sludge for use as a natural fertilizer in integrated aquaculture farming systems. Aquaculture America conference, World Aquaculture Society. Honolulu, HI. February 2020.

Guerdat, T., Rao, A., Fairchild, E., Hamlin, H., 2020. Assessing the acute and chronic toxic effects of potassium on rainbow trout (*Oncorhynchus mykiss*) and evaluating the mitigating effects of sodium on acute potassium toxicity. Aquaculture America conference, World Aquaculture Society. Honolulu, HI. February 2020.

Guerdat, T., 2020. Aquaponic Engineering and Design. Aquaponics Principles and Practices Workshop. Honolulu, HI. February 2020.

Accomplishments

This report for the first reporting cycle of the project is based primarily on the design and construction efforts performed to bring the research facilities online for operation and testing. The project has identified the myriad of integration possibilities between aquaculture and hydroponics, however this project is specifically focused on the two most economically-viable, and commonly practiced forms of integration: coupled and decoupled aquaponics. Coupled aquaponic systems share the same water between the fish and plant rearing systems, while decoupled systems capture nutrients from aquaculture and deliver them to the hydroponic systems as needed without returning any water/nutrients to the aquaculture systems similar to other animal agricultural productions systems. These system archetypes are representative of the current state of the industry, each posing different challenges to producers.

The research facilities at the UNH Kingman Farm were designed and have been built to accommodate both modes of operation for testing purposes. These research systems are fundamentally unique to the vast majority of aquaponic systems in practice currently as the focus on system design is based on meeting the needs of fish and plants through water treatment to facilitate food safety for consumers and producers. The UNH research systems are based on large-scale RAS water and wastewater treatment designs for scalability and to facilitate optimal water quality and quick adoption by existing industry practitioners. Wastes from each production "unit process" (i.e. fish tank, hydroponic plant bed) are channeled through the water and wastewater treatment systems first such that all water delivered to the fish and plants is considered "treated". Treated water is free of fish feces and is more biologically stable for use in hydroponic cropping systems, thereby improving both food safety as well as plant production. The following description of activities details the efforts of the researchers to achieve the goals of this research described above.

Goals

Objective #1

Major activities completed / experiments conducted
Nothing to report.

Data collected
Nothing to report.

Summary statistics and discussion of results
Nothing to report for this period.

Key outcomes or other accomplishments realized
Nothing to report for this period.

Objective #2

Major activities completed / experiments conducted
Mr. Joseph Tetreault, an Agricultural Sciences MS graduate student was conducted waste treatment research using wastewater generated from the aquaponic research facilities to develop fertilizer solutions for use in hydroponic cropping systems. Sample collection and waste treatment experiments were conducted using different microbial digestion techniques to solubilize the solid waste from tilapia production. The goal of his research was to optimize waste treatment processes for use in producing hydroponic fertilizer. Lab-scale bioreactors (20L) were used to conduct microbial digestion tests for determining the degree of solubilization achieved under aerobic and anaerobic conditions.

Data collected
The following operating parameters were measured to ensure aerobic and anaerobic conditions were met throughout the experiments: dissolved oxygen, oxidative reduction potential, pH, alkalinity, and total ammonia nitrogen. Data collected to determine the degree of solubilization included: total suspended solids, total dissolved solids, electrical conductivity, and nutrient concentrations in solid and liquid waste fractions analyzed by inductively coupled plasma atomic emission spectroscopy (ICP-OES).

Summary statistics and discussion of results
Nothing to report for this period.

Key outcomes or other accomplishments realized
Nothing to report for this period.

Objective #3

Major activities completed / experiments conducted
Nothing to report.

Data collected
Nothing to report.

Summary statistics and discussion of results
Nothing to report for this period.

Key outcomes or other accomplishments realized
Nothing to report for this period.

Objective #4

Major activities completed / experiments conducted
System operational parameters were established for the first part of the reporting period, and much effort was placed on establishing consistent and standardized operation across all three

greenhouse research facilities. The goal was to establish and maintain identical operating parameters under actual production conditions for replicated, farm-scale research. Intensive operational data collection was conducted for the second half of the reporting period and was successful in supporting multiple research objectives as listed below. Utilizing the preliminary data collected by the environmental engineering undergraduate team, an undergraduate Business Administration student, Mr. Dante Povinelli, conducted a robust analysis of the data and MS Excel model. This research and work was used to provide context for framing the economic research to be conducted.

Data collected
Operational data were collected during the reporting period for energy consumption (electricity and propane), water consumption, water quality analysis, fish production, and plant yield. These data are all preliminary and were used to validate the system design assumptions in order to adjust any operational parameters as necessary in order to obtain steady state operating conditions in each of the greenhouse systems.

Summary statistics and discussion of results
Nothing to report

Key outcomes or other accomplishments realized
Nothing to report

Objective #5

Major activities completed / experiments conducted
Nothing to report.

Data collected
Nothing to report.

Summary statistics and discussion of results
Nothing to report for this period.

Key outcomes or other accomplishments realized
Nothing to report for this period.

Objective #6

Major activities completed / experiments conducted
Two workshops were delivered during this reporting cycle. The first workshop was conducted in June 2019 as a hands-on, three-day aquaponics workshop hosted at the Kingman Farm AES, research data and operational guidelines were presented for aquaponic practitioners. Workshop participants walked away with knowledge and resources that will help them to operate aquaponic systems that are safe, sustainable, and profitable. The second workshop was conducted in

February 2020 in Honolulu, HI as a prelude to the Aquaculture America conference. System engineering, operation, and environmental control data were presented. Food safety and waste treatment research were also discussed and research to date presented to participants.

Data collected
Nothing to report.

Summary statistics and discussion of results
Nothing to report for this period.

Key outcomes or other accomplishments realized
Nothing to report for this period.

Opportunities for Training and Development

Three master's level graduate students were working towards a masters in Agricultural Sciences during the reporting period and completed their second year of study. Due to the COVID-19 restrictions placed on operations at the University, the students' research was delayed and not completed during this reporting period. All students were trained by Dr. Guerdat in the operation and maintenance of the research facilities. Each person played a supervisory role in the management of the facility. Since this was the second year of study, and due to COVID-19 restrictions and facility/University shutdowns, students solely focused on their academic coursework and research.

Dissemination of results to date

Multiple tours of the aquaponic greenhouses at UNH's Kingman Farm Agricultural Experiment Station were conducted with audiences including Extension professionals, school children, UNH alumni, and the general public. Presentations (oral and poster) were delivered at several national and internationally-attended conferences including the World Aquaculture Society Aquaculture America meeting in Honolulu, HI, the annual FDA Food Safety meeting in Portsmouth, NH, and the North Central Regional Aquaculture Center's annual conference in Columbus, OH. The audiences have ranged from producers to policy makers to industry professionals as well as academic researchers.

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Changes/Problems

Describe major changes/problems in approach and reason(s) for these major changes. If applicable, provide special and/or additional reporting requirements specified in the award Terms and Conditions.

As with any large-scale agricultural operation, challenges were presented in the form of malfunctioning equipment causing operational setbacks. However, all efforts were made to address issues in a timely manner and the result was a successful year of research. Malfunctions included drum screen filters not backwashing properly and causing loss of excess water from the systems, environmental control software programming problems and incorrect environmental parameters. However, the single largest challenge of this reporting period was the COVID-19 forced shutdowns of the University and all research facilities. As such, students and faculty alike struggled to gather and collect enough data to continue the research working remotely. All facilities were depopulated, drained and dried in March 2020. As such, all research was terminated immediately, and researchers were forced to pivot and develop revised research objectives with the data available at the time of shutdown.

Plans for next reporting cycle

The research facilities were depopulated, drained and dried, and the University was shut down due to COVID-19 required restrictions. Additionally, Dr. Guerdat departed UNH in March 2020, and the University expressed a direct interest in terminating the research altogether instead of trying to manage the project through Cornell. As such, there are no future plans for continuing the research.