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Aquaponics at WMU: A brief history

Introduction:

Aquaponics is an agricultural method that integrates aquaculture (fish farming) and hydroponics (soilless plant growth) into a single, recirculating system. The system relies on the mutual symbiosis (beneficial species interactions) of fish, bacteria and plants. The fish create waste ammonia that is converted by bacteria into nitrites and then nitrates, which are an excellent source of plant nutrition. The plants then absorb this bioavailable nitrogen, filtering and cleaning the water before it is returned to the fish tank. This process, known as the nitrogen cycle, occurs naturally in ecosystems such as lakes and wetlands. Mimicking these ecological functions allows aquaponics to produce less waste, use less water, and make more efficient use of space than conventional agriculture. The Western Michigan University (WMU) Office for Sustainability has operated an aquaponics program since 2012.

Beginnings:

A 2012 Student Sustainability Grant (SSG) marked the start of the Office's aquaponics program. SSG funds are dedicated to student-led initiatives that improve campus sustainability. The original proposal for the SSG included vertical grow towers, a transparent fish tank, black soldier fly larvae (BSFL) composting, and vermicomposting. After being awarded the SSG funds, students completed further research and revised their design, selecting two ebb and flow (E&F) beds for the hydroponic system. In an E&F system, plants grow in a bed of high-surface-area media, which is periodically flooded with water and then automatically drained by a bell siphon. E&F beds are less complicated to construct and operate than vertical growth systems, making them an appealing option for beginning aquaponics practitioners, and they allowed the team to place red wiggler worms (*Eisenia fetida*) directly into the media to vermicompost excess fish waste. Researchers also chose an opaque fish tank to avoid excessive algae growth, and they postponed BSFL composting plans as potential future research. During 2012, students effectively raised tilapia (*Oreochromis* spp.) in the system and grew leafy greens, including herbs and duckweed.

System Refinement:

After the success of the initial SSG, Office leadership decided to adopt the aquaponics project as an ongoing program with student employee positions paid through funding from the student green jobs budget. In 2013, student employees expanded the design of the aquaponics system to examine new hydroponic methods and crops, focusing on leafy green vegetables such as lettuce. The revised system included three forms of hydroponics: E&F, deep water culture

(DWC), and nutrient film technique (NFT). In DWC systems, plants grow in a raft floating over a pool of aerated water; the roots hang below the raft, absorbing water and nutrients. In an NFT system, plants grow in channels through which water constantly flows; roots absorb water and nutrients as they hang into the channel. The second E&F bed was repurposed as a DWC basin, and the NFT channels were constructed from vinyl fence posts. During Summer 2014, an excess of solid waste clogged system filters and created a spike in ammonia levels; the resulting ammonia toxicity and low dissolved oxygen levels killed one-third of the tilapia. More tilapia were purchased, and summer researcher Carlos Daniels planned to implement automation systems and additional filtration to prevent future die-offs.

In Fall 2014, students constructed and installed two swirl filters, also known as vortex filters, to provide mechanical filtration of fish waste by redirecting water flow, which forces the heavy solids to settle out of the water column, sedimenting at the bottom of the filter. Each swirl filter was made of PVC components and a plastic 5-gallon water jug commonly used in workplace water coolers. Researchers also installed an APEX Fusion automation system in Fall 2014 to provide 24-hour monitoring of system pH, temperature, dissolved oxygen levels, and energy consumption. The system was set to alert researchers to poor water quality parameters and to turn outlets on and off under specific water quality conditions. For example, when dissolved oxygen dropped to unsafe levels, researchers received text alerts, and the water heater turned on only when the water temperature dropped below the preferred temperature for tilapia culture.

Continued Research:

Throughout the history of the program, students have researched the best crops, pumps, fish feed, pest management, aquaculture species, hydroponic techniques, and filtration methods for aquaponics. During Fall 2014 and Spring 2015, the aquaponics team completed in-depth academic research, preparing a proposal to construct a pilot commercial aquaponics operation in a greenhouse at the WMU Gibbs House permaculture site. This proposed system would employ a cylindrical fish tank, a swirl filter, a fish feed produced on-site, marbled crayfish, rainbow trout, airlift pumps, vertical grow towers. The cylindrical fish tank would prevent the anaerobic "dead zones" that may arise in tanks with corners, and a large swirl filter could be built inexpensively from a 55-gallon plastic barrel commonly used for shipping food. The food for the fish would be produced on-site from BSFL used in a Gibbs House composting project, spirulina algae grown with excess fish waste, and marbled crayfish.

Marbled crayfish (*Procambarus fallax* f. *virginalis*) are an asexually-reproducing variant of the Florida-native slough crayfish (*Procambarus fallax*). Also known as Marmorkrebs, these animals were discovered in a German pet shop in the 1990s and reproduce through parthenogenesis, meaning that all individuals are self-cloning females. The lack of males in the population results in a much less territorial and aggressive crayfish community, allowing for a higher stocking density. Because a single specimen can produce a large number of offspring, the marbled crayfish has a strong potential for invasiveness, and researchers would have to develop a containment protocol for these crustaceans.

Researchers selected a new fish species for their proposal because the cold winters of Michigan would result in an unsustainable use of heating energy if they were to raise tilapia. Students proposed using rainbow trout (*Oncorhynchus mykiss*) because they are a relatively fast-growing coldwater fish that can survive the Michigan climate. Students also investigated the potential use of freshwater mussels for additional biofiltration in an aquaponic polyculture, but they decided to postpone any real-world application of mussels for future researchers.

External Design Research and Accolades:

In Fall 2014 and Spring 2015, several Office employees, including the aquaponics team, participated in a national sustainable design competition outside of their employment at the Office. Student employees Ramon Roberts-Perazza, Max Hornick, Kelsey Pitschel, and Eli Lowry competed in Wege Prize 2015 with student Cara Givens and guidance from Aquaponics Lead Carlos Daniels, Permaculture Coordinator Joshua Shultz, and Green Metrics Intern Kyle Simpson. Wege Prize is a competition in which interdisciplinary five-person teams of undergraduates from different colleges design a business or product that will promote a circular economy, which is an economy in which waste products are recaptured as raw materials for the next round of production. The WMU team planned a modular aquaponics and composting business called the Local Loop Farm, designed to fit within the average city block. This design integrated tilapia aquaculture, hot composting to heat the water as needed for tilapia, DWC hydroponics, spirulina production, marbled crayfish, and BSFL composting. The team received press coverage and public accolades when they won the Wege Prize 2015 grand prize: $15,000 distributed equally among teammates.

Recent Activity:

In 2015, summer researcher Max Hornick learned that rainbow trout are not well-suited to aquaponics because they require near-zero concentrations of nitrates to survive. The researcher decided to revise the Gibbs House proposal to reflect a change in fish species and write a first-draft of an additional proposal, this time for an upgrade to the demonstration system already located in the Office. The revised Gibbs House design would use yellow perch (*Perca flavescens*) rather than rainbow trout because these native, coolwater fish are more tolerant of adverse water conditions, including relatively high nitrate levels.

In Fall 2015, aquaponics teammates initially worked on a revised Gibbs House design, but ultimately the team designed an upgrade to the Office demonstration system instead. This upgrade was designed to be durable, low-maintenance, highly efficient, and adaptable; to generate a minimum produce output of 2 lbs per week; and to demonstrate the potential for outdoor and commercial aquaponics in Michigan. Researchers also decided to include integrated pest management in the design after battling a system infestation of fungus gnats. Students finalized the design and constructed the system during Spring 2016.

The system uses two hydroponic methods that have proved successful in commercial aquaponics: DWC and vertical grow towers. The system includes two DWC basins and eight vertical grow towers. Four of the 5-foot towers are ZipGrow towers purchased from Bright Agrotech, while the other four are constructed of vinyl fence posts and Bright Agrotech's ZipGrow filter media. Cross-linked polyethylene, a closed-cell foam commonly used for marine flotation, was used for the DWC rafts because of its durability and UV-resistance. The DWC pools are aerated using "paper" style diffusers, small tubes of paper-thin plastic with tiny perforations. This helps ensure sufficient and consistent aeration throughout the basin.

Researchers chose to use LED grow lights for all plant systems, the most energy-efficient form of lighting currently available. Two new types of LED grow lights are used with the vertical growth systems; one emits blue wavelengths, while the other emits both red and blue wavelengths. Blue light is the most important part of the spectrum for vegetative growth, while red light is essential for flowering and fruiting of plants. Because the system is being used to grow leafy greens and not fruiting plants, researchers will compare the impact of blue-only lighting to red-and-blue lighting.

The upgrade uses two new forms of filtration: a radial flow separator/settler (RFS) and a sand and gravel-filled particulate biofilter. The RFS provides mechanical filtration by redirecting water and allowing heavy solids to sediment at the bottom. This filter was constructed using PVC components, a 15-gallon inductor tank, and a large funnel. In the biofilter, the mechanically filtered water is aerated as it passes through a large surface area of gravel and sand, which is colonized by nitrifying bacteria that convert fish waste ammonia to nitrate plant fertilizer. The biofilter was constructed from a 30-gallon plastic barrel, bulkhead fitting, silicone, PVC components, and a sheet of polycarbonate.

Two potted, carnivorous plants native to Michigan will help provide pest management around the system: a northern purple pitcher plant and a round-leafed sundew. The northern purple pitcher plant (*Sarracenia purpurea purpurea*) catches insects and other small prey using specialized, pitcher-like leaves with small hairs inside them, while the leaves of the round-leafed sundew (*Drosera rotundifolia*) produce a sticky enzyme to trap and digest prey.

In the interest of educating Office visitors, the team installed a viewing window in the fish tank which will allow people to easily observe the fish. All system components are separated by valves, and both filters have bypasses, allowing the team to isolate dysfunctional elements as needed for troubleshooting and parts replacement. The fish used in the upgraded system will be 45 health-certified, feed-trained yellow perch fingerlings purchased from Laggis' Fish Farm, a regional aquaculture business located in nearby Gobles, Michigan. Researchers plan to grow green curly kale, romaine lettuce, spinach, parsley, cilantro, and basil in the new system because they are popular and profitable crops.

Future of the Program:

As students operate the latest model of the system, more detailed data will be collected, leading to new insights and improvements. Analyses conducted will compare the success of the different plant growth systems, planting density, lighting, and crops. Additional future research may include formulating a sustainable yellow perch diet composed primarily of BSFL, evaluating the effects of freshwater mussel filtration in an aquaponic polyculture, raising marbled crayfish to consume excess fish waste, and designing and constructing a pilot commercial-scale outdoor aquaponics system in a greenhouse at the WMU Gibbs House.