Introduction to Aquaponics

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Definition

- Aquaponics – Aquaculture + Hydroponics

- Basic idea is:
  - Multiple uses of water
  - Recover as much **value** from inputs as possible
  - **Minimize** negative environmental impact
  - Sustainable system
Who can/should do aquaponics?

- Backyard hobbyists
- Community groups?
- Commercial scale?
  - Fish producers who want to diversify
  - Usually shouldn’t go the other way
The AU approach

- We are trying to design and operate a commercial-scale system.
- Primary process is tilapia production using biofloc technology.
- De-coupled system
- Multiple vegetable species (other plants as well)
What are we growing in aquaponics?

What are you growing in an aquaponic system?

At least 3 things:

1. Aquatic animals (usually fish)
2. Plants (high value)
3. Bacteria
Fish

- Various types of fish can be used, but we are typically limited in our selection.

1. Need a warm water species (typically).
   1. Rainbow trout (13-15 °C; 55-60 °F); Nile tilapia (21-29 °C; 70-85 °F)

2. Needs to be able to survive well in RAS.
   1. Confinement, high levels of nutrients in water, etc..

   1. Protein = N
Nile Tilapia

- Work nicely in most aquaponic systems

- Tilapia are tough fish.
  - Tolerate wide range of pH
  - Tolerate high concentration of nitrates
  - Vigorous eaters
  - Eat primary feed and partially digested feed

- Adaptive to many environments.

- Value?
Plants

- Need to grow high-value plants.
- Species that are normally grown in hydroponics.
  1. Lettuce
  2. Cucumbers
  3. Peppers
  4. Tomatoes

- With some exceptions possibly...
Two major types of bacteria are crucial to success in aquaponics:

- *Nitrosomonas* spp.
- *Nitrobacter* spp.

Both types must be present to effectively transform waste into fertilizer.
How does it work?

The science behind aquaponics relies on an understanding of the nitrogen cycle.

In natural systems, nitrogen is cycled from one form to another to another, and so on...

Aquaponics utilizes this natural cycle to produce protein and vegetables in the same system.
The Basic Idea

1. Fish convert protein (organic N) into ammoniacal-N excreted in feces, urine, and through gills.

2. Bacteria convert ammoniacal-N to nitrate-N.

3. Plants remove nitrate-N from water.
System Design Options

- Continual recirculation (circular design)
  - Fish – plants – fish – plants

- De-coupled system (linear design)
  - Fish – plants – plants – plants
Primary process is fish production in any aquaponic system. Either the fish are being intensively produced for sale, utilized as fertilizer factories, or both. Re-tasking the fish waste leads to the secondary and tertiary processes.
Figure 2: Systems schematic of the Auburn University aquaponics facility
- High-protein, soy-based feed and water are the primary inputs into the system.

- Track the water movement through the system.

- Nutrients (N) move with water through the system.

- Multi-use water and nutrients.
Figure 1: Auburn University’s aquaponics system, with the tilapia greenhouse at top left, the vegetable greenhouse at lower left and the algae cultivation and water treatment systems at right.
University of the Virgin Islands (UVI) System
Nitrogen is present in multiple forms in our environment.

- $\text{N}_2$ gas in atmosphere (70%)
- Organic N (amino acids, proteins, DNA, etc.)
- Ammoniacal N – Ammonium ($\text{NH}_4^+$) and ammonia ($\text{NH}_3$)
- Nitrites ($\text{NO}_2^-$)
- Nitrates ($\text{NO}_3^-$)
Bacteria are our friends

- Bacteria are the workforce behind aquaponics
- Will not work at all without bacteria
- We want to grow the right types and set up the right conditions for them to be happy
  - *Nitrosomonas* spp.
  - *Nitrobacter* spp.
A biofilter is material that allows bacteria to colonize and do the work we want them to do.

In this case, *nitrification*.

Many different types of biofilters are available.

- Shredded PVC (surface area) – 3D printed media – bead filters - flocculants within fish production water
Biofilter

- For biofilters to be most effective, we need constant agitation of the water.

- The biofilter can be within the water column of the RAS or outside it.
Biofilter

- Low-cost system that we use at AU: Bio-floc technology (BFT)

- Water column in RAS is the biofilter.
Biofloc Technology (BFT)

- Bacteria *flocculate* together, when present in very high concentrations, to form “bioflocs”

- Bioflocs are suspended in the water column through constant aeration (bubbling)

- Bacteria in bioflocs carry out nitrification!
Figure 1: Auburn University’s aquaponics system, with the tilapia greenhouse at top left, the vegetable greenhouse at lower left and the algae cultivation and water treatment systems at right.
So, solids in the system are constantly agitated via aeration.

Solids = solid waste, bioflocs, partially digested waste, etc..

Tilapia will eat primary feed and bioflocs.

Increases FCR (Feed Conversion Ratio)!
What do we do with the solids?

- We must remove the solids on a regular basis.

- Can repurpose solids –
  1. Organic soil amendment
  2. Horticultural substrate amendment
  3. Anaerobic digestion – biogas
  4. Fermentation – lactic acid production

- Liquid fraction = nitrates
Conical Clarifier: Passive clarification
A = primary clarifier with baffle
B = secondary clarifier without baffle
C = solids removal sump

Clarified water is pumped from clarifier B using an irrigation pump
Active Filtration

**TURBO-DISC AUTOMATIC FILTER SYSTEMS**

**Filtration Mode**

Water enters the inlet and is filtered through the disc stack from the outside to the inside.

The discs are compressed by the disc cap on top of the disc stack.

The **Turbo-Element**, at the base of the cartridge, spins the incoming water, keeping heavier debris in suspension and minimizing backflush frequency.

**Backflush Mode**

Filtered debris collects on the exterior of the disc stack and across the depth of the discs, while filtered water exits through the outlet, either inline or 90 degrees to the inlet.

When the filter cartridge requires cleaning:

- The disc cap lifts hydraulically, decompressing the disc stack.
- A uniform backflush (shown by the green arrows) is then applied through the molded spray nozzles (shown by the orange arrows and white spray) centrifugally spinning and spraying the discs clean. Purge water and debris exit through the inlet.

When the backflush cycle is complete, the disc cap re-compresses the disc stack and normal filtration is resumed.
Solids are Bad!

- Whether we use **water culture** or soilless culture, we can’t have too many solids in our nutrient solution.
Solids are Bad!

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*How it works*

1. Under normal conditions, there is a slight pressure differential across each orifice in the silicone diaphragm.

2. As a particle encounters the orifice, there is a momentary obstruction, causing the differential pressure across the orifice to increase greatly. This pushes the particle through the expanding orifice.

3. The particle is then flushed through the orifice, which instantly returns to its normal size. Normal pressure conditions are restored. The particle continues through the remaining orifices in the diaphragm and out of the NonStop emitter.
What do we have to work with?

<table>
<thead>
<tr>
<th></th>
<th>Fish Feed</th>
<th>Fish Manure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude Protein Dry</td>
<td>35.7%</td>
<td>22.8%</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>5.7%</td>
<td>3.6%</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>1.2%</td>
<td>0.9%</td>
</tr>
<tr>
<td>Potassium</td>
<td>1.5%</td>
<td>0.2%</td>
</tr>
<tr>
<td>Calcium</td>
<td>1.2%</td>
<td>2.0%</td>
</tr>
<tr>
<td>Magnesium</td>
<td>0.3%</td>
<td>0.2%</td>
</tr>
<tr>
<td>Sodium</td>
<td>0.2%</td>
<td>0.5%</td>
</tr>
<tr>
<td>Iron (ppm)</td>
<td>250</td>
<td>3575</td>
</tr>
<tr>
<td>Manganese (ppm)</td>
<td>99</td>
<td>544</td>
</tr>
<tr>
<td>Copper (ppm)</td>
<td>21</td>
<td>99</td>
</tr>
<tr>
<td>Zinc (ppm)</td>
<td>125</td>
<td>323</td>
</tr>
</tbody>
</table>
What happens to N when you feed fish?

- Fish Poop: 33%
- Fish Flesh: 34%
- In Solution: 33%
Ammonia (NH₃): Ammonium (NH₄⁺)
TAN

Nitrosomonas

Nitrite (NO₂⁻)

Nitrobacter

Nitrate (NO₃⁻)

\[ \text{NH}_4^+ + \text{NO}_3^- \rightarrow \text{H}^+ + \text{H}^+ \]
DENITRIFICATION

Nitrate (NO$_3^-$)

Nitrogen Gas (N$_2^-$)

H$_2$O

H$^+$

H$^+$

pH

H$^+$

H$^+$
If we want to maximize our efficiency it is in our best interest to maximize nitrification

Much debate in aquaponics world about this

At AU, we have taken the commercial food production approach to the problem

Some other institutions have attempted primarily to maintain balance in the system
Nitrification

- *Nitrosomonas* spp.
- *Nitrobacter* spp.

- Most efficient (happiest?) at pH 7.5 – 8.5
- Plants are happiest at 5.8 – 6.5

- What pH do we shoot for?

- Nitrification will drive pH down!
Finding the right pH in our system

- At this point, AU aquaponics system runs at pH 6.2 – 6.8.
- Plants are happy (at least pH-wise)
- Avg. daily nitrate concentrations = 200 – 600 ppm
- 200 – 600 ppm NO₃-N = 45 – 135 ppm N
## Recommended Nutrient Concentrations
### Aquaponics vs Hydroponics

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Aquaponics (mg/L)</th>
<th>Hydroponics (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium</td>
<td>10.0 – 82.0</td>
<td>150.0</td>
</tr>
<tr>
<td>Magnesium</td>
<td>0.7 – 13.0</td>
<td>50.0</td>
</tr>
<tr>
<td>Potassium</td>
<td>0.3 – 192.0</td>
<td>150.0</td>
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<tr>
<td><strong>Nitrate</strong></td>
<td><strong>0.4 – 82.0</strong></td>
<td><strong>115.0</strong></td>
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<td>Phosphate</td>
<td>0.4 – 15.0</td>
<td>50.0</td>
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<tr>
<td>Sulfate</td>
<td>0.1 – 23.0</td>
<td>113.0</td>
</tr>
<tr>
<td>Iron</td>
<td>0.03 - 4.3</td>
<td>5.0</td>
</tr>
<tr>
<td>Manganese</td>
<td>0.01-0.20</td>
<td>0.5</td>
</tr>
<tr>
<td>Copper</td>
<td>0.01-0.11</td>
<td>3.0</td>
</tr>
<tr>
<td>Zinc</td>
<td>0.11-0.80</td>
<td>0.05</td>
</tr>
<tr>
<td>Molybdenum</td>
<td>0.01-0.23</td>
<td>0.05</td>
</tr>
<tr>
<td>Boron</td>
<td>0.01-0.17</td>
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• We may get more nitrification at higher pH

• Increase plant production!

• Ultimately, we want to design a system in which all of our nitrates and water are being utilized within the system (i.e. minimal waste)

• How do we increase pH?
- Our water has low alkalinity.
- Add lime to the water.
- Hydrated lime – Ca(OH)$_2$ (very caustic, use with caution)
- Currently, we add lime weekly.
- We would need to add lime daily to maintain pH >7
Problems with high pH?

- A major problem with high pH in fish production is the higher presence of “un-ionized” ammonia

- $\text{NH}_3$

- $\text{NH}_4$ much less toxic to fish

- $[\text{NH}_3] > 5 \text{ mg / L} = \text{dead fish}$
• In theory: higher pH = more bacteria = more nitrification = less TAN

• What about other nutrients?

• We supplement potassium (K), calcium (Ca), and Iron (Fe)

• Muriate of potash (K), hydrated lime (Ca), chelated iron (Sprint 330)
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AU Approach

- Focus on commercialization of technology.
- Increase nitrification
- Decouple fish and plant production.

Spread nitrate-rich water to large population of plants = $$$

Dutch Bucket Culture / Beit Alpha Cucumbers
No-Clog Emitters (Bowsmith)
AU Approach

- Focus on commercialization of technology.
- Increase nitrification
- Decouple fish and plant production.
  Spread nitrate-rich water to large population of plants = $$$
- High-protein, soy-based feed and water are the primary inputs into the system.

- Track the water movement through the system.

- Nutrients (N) move with water through the system.

- Multi-use water and nutrients.
Fish

- Cucumbers
- Tomatoes
- Peppers
Why decouple?

- Pesticides, even organic options, are often highly toxic to fish.

- Maximizing water use efficiency does not mean the same thing as recirculating water over and over.

- Diseases?
Is Aquaponics commercially viable?

- The technology works. Proven in several, different systems.
- Can you make $?
- Is it safe??
The Current Situation

- Intensive aquaculture (RAS) is not profitable, in many cases.
  - Low cost of imported fish
  - Expensive to process

- “You make money on the plants”

- So, why aquaponics?