TOMATO PRODUCTION IN AQUAPONIC SYSTEM: MASS BALANCE AND NUTRIENT RECYCLING

Zala Schmautz*¹, Andreas Graber¹,³, Alex Mathis¹, Tjaša Griessler Bulc² and Ranka Junge¹

¹ Zurich University of Applied Sciences, Institute Natural Resource Sciences, Grüental, Wädenswil (Switzerland)
² University of Ljubljana, Faculty of Health Sciences, Ljubljana (Slovenia)
³ Urban Farmers AG, Zurich (Switzerland)
Presentation summary

1. *Introduction*: Aquaponic and nutrients
2. *Methods*: Experimental design, system monitoring, and analyses
3. *Results*: Nutrient balance, losses, cycles
4. *Conclusion*
Aquaponics – How does it work?

Fish feed
1kg

Fish harvest
700 g

Evapotranspiration
290 L

Evapotranspiration
290 L

Fish sludge
2 L

Fish harvest
5 - 10 kg

“fish water”

Schmautz et al., 2015
Nutrients in an aquaponic system

- Single loop AP systems → to balance the nutrients in the system [1].
  → Mismatch between nutrients required by fish and nutrients required by plants.

- Some studies reported that aquaculture effluents contain sufficient levels of N, P, B, C, while levels of K, Ca, and Fe are generally insufficient [2,3,4].
  → There are a few studies that allow complete budgeting on the nutrients: complete budgeting on a very small scale [4,5], or only very few nutrients on a bigger scale [6,7,8].


Schmautz et al., 2015
To examine the distribution and possible losses of nutrients within the aquaponic system by determining the mass balance for particular macronutrients (C, N, P, K, Ca, and Mg) and micronutrients (Fe, Mn, Zn, and Cu).
Design of “Waedenswil” aquaponic system

Three identical experimental aquaponics systems were installed in a foliar greenhouse on the ZHAW Campus in Waedenswil (Switzerland).

Legend:
- System A
- System B
- System C
- Biofilter
- Solids thickening unit
- Solids removal unit
- Fish tank
- Plant sump
- Tomato plant

Schmautz et al., 2015
One AP unit in detail

Schmautz et al., 2015
The aquaculture subunit

Methods

Schmautz et al., 2015
The hydroponic subunit

Methods

Legend:
- valve
- water counter
- water flow
1 - water pump with permanent flow
2 - water pump with timer regulated flow
3 - water pump with level controlled flow

Schmaultz et al., 2015
In spring 2014, the "Waedenswil" aquaponic system was stocked with Gardenberry tomatoes (*Lycopersicon lycopersicum*) and Nile tilapia (*Oreochromis niloticus*).
## System monitoring

<table>
<thead>
<tr>
<th></th>
<th>Monday</th>
<th>Tuesday</th>
<th>Wednesday</th>
<th>Thursday</th>
<th>Friday</th>
<th>Saturday</th>
<th>Sunday</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fish check</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>System check</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Fish feeding</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>pH control</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Drum filter cleaning</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>RFS cleaning</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Hydroponic filters</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Harvest</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Pruning</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Water analysis</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adding fertilizers</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Schmautz et al., 2015
System water analyses

- Weekly water analyses: TP, NO$_3$-N, NO$_2$-N, NH$_4$-N, K, Fe, Ca, Mg, and B with a spectrophotometer.

- Target parameter values for the system water were determined according to the standard tomato nutrient requirements.

<table>
<thead>
<tr>
<th></th>
<th>TP</th>
<th>NO$_3$-N</th>
<th>NO$_2$-N</th>
<th>NH$_4$-N</th>
<th>K</th>
<th>Fe</th>
<th>Ca</th>
<th>Mg</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>31 Mar - 14 Sep '14</td>
<td>40</td>
<td>160</td>
<td>0</td>
<td>0</td>
<td>250</td>
<td>3</td>
<td>200</td>
<td>50</td>
<td>0.2</td>
</tr>
<tr>
<td>15 Sep - 5 Nov '14</td>
<td>40</td>
<td>160</td>
<td>0</td>
<td>0</td>
<td>234</td>
<td>3</td>
<td>130</td>
<td>24</td>
<td>0.2</td>
</tr>
</tbody>
</table>
Determination of the nutrient balance

The primary inputs and outputs of the aquaponic system were used to determine the nutrient balance:

Schmautz et al., 2015
### Sampling and analysed nutrients from 12 Jun ‘14 until 5 Nov ‘14

<table>
<thead>
<tr>
<th>SAMPLE</th>
<th>IN</th>
<th>OUT</th>
<th>SAMPLING DATE</th>
<th>ANALYSED NUTRIENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tap water</td>
<td>X</td>
<td></td>
<td>25 Jul, 13 Oct, 5 Nov</td>
<td>NO$_3$-N, NO$_2$-N, NH$_4$-N, P, K, Ca, Mg, Fe</td>
</tr>
<tr>
<td>Fish feed</td>
<td>X</td>
<td>Each new fish feed</td>
<td></td>
<td>C, N, P, K, Ca, Cu, S, Mg, Mn, Zn, Fe</td>
</tr>
<tr>
<td>Fish</td>
<td>X</td>
<td></td>
<td>/</td>
<td>Literature data</td>
</tr>
<tr>
<td>Sludge</td>
<td>X</td>
<td>approx. every 14 days</td>
<td></td>
<td>C, N, P, K, Ca, Cu, S, Mg, Mn, Zn, Fe</td>
</tr>
<tr>
<td>System water</td>
<td>X</td>
<td></td>
<td>Weekly (1 Apr – 5 Nov)</td>
<td>NO$_3$-N, NO$_2$-N, NH$_4$-N, P, K, Ca, Mg, Fe</td>
</tr>
<tr>
<td>KOH and Ca(OH)$_2$</td>
<td>X</td>
<td></td>
<td>/</td>
<td>Information given by supplier</td>
</tr>
<tr>
<td>Nutrient sup. (solid)</td>
<td>X</td>
<td>5 Nov</td>
<td></td>
<td>C, N, P, K, Ca, Cu, S, Mg, Mn, Zn, Fe</td>
</tr>
<tr>
<td>Nutrient sup. (liquid)</td>
<td>X</td>
<td>5 Nov</td>
<td></td>
<td>P, K, Ca, Cu, S, Mg, Mn, Zn, Fe</td>
</tr>
<tr>
<td>Substrate</td>
<td>X</td>
<td>31 Mar</td>
<td></td>
<td>C, N, P, K, Ca, Cu, S, Mg, Mn, Zn, Fe</td>
</tr>
<tr>
<td>Green cut</td>
<td>X</td>
<td>12 Jun, 25 Jul</td>
<td></td>
<td>C, N, P, K, Ca, Cu, S, Mg, Mn, Zn, Fe</td>
</tr>
<tr>
<td>Whole green biomass</td>
<td>X</td>
<td>12 Jun, 25 Jul, 5 Nov</td>
<td></td>
<td>C, N, P, K, Ca, Cu, S, Mg, Mn, Zn, Fe</td>
</tr>
<tr>
<td>Tomato fruits</td>
<td>X</td>
<td>12 Jun, 7 Aug, 16 Oct</td>
<td></td>
<td>C, N, P, K, Ca, Cu, S, Mg, Mn, Zn, Fe</td>
</tr>
<tr>
<td>Roots</td>
<td>X</td>
<td>5 Nov</td>
<td></td>
<td>C, N, P, K, Ca, Cu, S, Mg, Mn, Zn, Fe</td>
</tr>
<tr>
<td>Substrate with roots</td>
<td>X</td>
<td>5 Nov</td>
<td></td>
<td>C, N, P, K, Ca, Cu, S, Mg, Mn, Zn, Fe</td>
</tr>
</tbody>
</table>

Schmautz et al., 2015
General results

- According to scientific literature, aquaponic systems require a daily fresh water addition of 1-1.5% of the total system’s volume; the “Waedenswil” aquaponic system required an average daily water addition of 1.6%.
- Production of the “Waedenswil” aquaponic system was in total **430 kg of tomato fruits** and **60 kg of fish mass**.
Input of nutrients into the system

Schmautz et al., 2015
Output of nutrients from the system

* - Green biomass = green cut + whole green biomass

Schmautz et al., 2015
Losses from the system

- Considerable losses occurred in the mass balance. Most of them could probably be explained by not obtaining our own fish data and only a small amount of analysed sludge samples.

- **AVERAGE LOSS (% Input):**

<table>
<thead>
<tr>
<th></th>
<th>C (kg)</th>
<th>N (kg)</th>
<th>P (kg)</th>
<th>K (kg)</th>
<th>Ca (kg)</th>
<th>Cu (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loss</td>
<td>36%</td>
<td>49%</td>
<td>77%</td>
<td>69%</td>
<td>82%</td>
<td>16%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Mg (g)</th>
<th>Mn (g)</th>
<th>Zn (g)</th>
<th>Fe (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loss</td>
<td>38%</td>
<td>-2%</td>
<td>45%</td>
<td>25%</td>
</tr>
</tbody>
</table>

Schmautz et al., 2015
Phosphorus balance

Fish feed 72%  
Nutrient supplements 28%  
1260 g  
490 g  

Green waste and roots 41%  
156 g  
126 g  

Fish 28% (Loss?)  
Fish sludge 1% (Loss!)  
Tomato fruits 32%  

Schmautz et al., 2015
Phosphorus balance

**Input:**
- Fish feed: 1,260 g (72%)
- Nutrient supplements: 490 g (28%)

**Output:**
- Fish: 110 g (28%)
- Fish sludge: 1 g (1%)
- Green waste and roots: 156 g (41%)
- Tomato fruits: 126 g (32%)

**Loss:**
- "cleaned water": 1,357 g

Schmautz et al., 2015
Conclusion

• To our knowledge, this study was the first attempt to nearly complete budgeting of a wide array of nutrients.

• Research on fish feeds adapted to the aquaponic systems is needed. However, it is open to debate whether packaging nutrients into fish feeds makes sense from the standpoint of animal welfare and resource efficiency in order to minimize mismatch between the RAS and HP.

• Extracting the nutrients (P!) from the fish sludge combined with targeted nutrients addition in to the HP currently seems to be the best option.

Schmautz et al., 2015
Just a normal Friday afternoon ...
Thank you!

Photo: Peter Buchmann / SRF