Using green waste biogas slurry as nutrient source for a NFT hydroponics system combined with an MBBR

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Abstract

Traditional mineral hydroponic solutions are resource intensive and energy demanding, so there is an interest to find more sustainable alternatives of nutrient sources for soilless cultivation.

A proof-of-concept experiment was built and operated in Malmö, Sweden between February 2019 and May 2019. A nutrient film technique (NFT) system combining horizontally slanted ZipGrow™ towers and a moving bed biofilm reactor (MBBR) was set-up with *Lactuca sativa*, *Ocimum basilicum*, *Beta vulgaris subsp. vulgaris*, and *Pisum sativum*. The MBBR was seeded with water from a mature aquaponics system, and then fed weekly with 200-600 mL of the supernatant of a centrifuged slurry resulting from the biogas production of green waste, from a waste treatment plant in Helsingborg. The objective was to test if the nutrients available in the green waste biogas slurry would be available in soluble form after passing by a nitrifying MBBR reactor, enabling the growth of the aforementioned crops.

The experiment ran for 90 days, and by the end the plants were visibly healthy, had grown to a full harvest size, and showed no signs of discoloration or deficiencies. However, aphids (*Aphidoidea*) were found in plants frequently due to external contamination and an indoor setting protecting them from predators, and plant growth was disrupted frequently due to the high solids contents of the green waste biogas slurry solution clogging the feeding pipes and the ZipGrow™ matrix media.

In conclusion, this proof-of-concept experiment has shown that a NFT hydroponics system can work for the production of crops such as lettuce, basil, swiss chard, and snap pea, using a byproduct of a green waste biogas process as the nutrient solution, although future attempts should circumvent the clogging potential of such a nutrient solution in the system plumbing.

Keywords: hydroponics, bioponics, green waste, slurry, biogas, organic waste

1. Introduction

Current mineral based hydroponic solutions provide great control in soilless cultivation, and great optimization at the different stages of growth for a variety of plants. However, they have raised sustainability concerns as they are resource intensive and energy demanding, while also producing a lot of waste. The activities involved in the production of mineral based hydroponic solutions include: mining, ore treatment, chemical processing, and transportation. The whole process requires fossil fuels, electricity, chemicals, and water, to produce the nutrient solution. On the other hand, mining waste, greenhouse gasses, and wastewater are also produced as a consequence (Dumitrescu, 2013).

Biogas production from municipal green waste is a well understood process. The clippings from municipal parks and trees are collected and placed in an anaerobic digester, where methanogens degrade the compounds, producing methane that can be used as an energy source. The process occurs in a sealed chamber and after the digestion process there is a slurry residue with harder to digest solids as well as a highly concentrated liquid. This biogas slurry is thus a secondary product from the anaerobic fermentation and can be used as an organic fertilizer in a wide range of soil amendment applications.

Recently, interest has been placed in the application of such green waste biogas slurry in a hydroponic context. A thesis from Stockholm, Sweden details the feasibility of such a nutrient source (Alexandersson & Tran, 2017), while IKEA & Biond have showcased a pilot where salad served in an IKEA kitchen is grown from the kitchen’s treated organic waste via a biogas slurry after such waste has produced biogas (Cision, 2019). The use of a green waste biogas slurry in a hydroponics setting rather than a soil setting would provide water savings and faster growth, however it is unclear if having the green waste biogas slurry as the only nutrient source would be enough for all types of plants, or if additional supplementation would be needed.

This proof-of-concept system had the goal to test if the nutrients available in the resulting green waste biogas slurry from a biogas producing plant would be available in soluble form after passing through a Moving Bed Biofilm Reactor (MBBR), where surface area is provided with plastic media to promote the growth of nitrifying bacteria. A variety of plant species were chosen, such as lettuce (*Lactuca sativa*), basil (*Ocimum basilicum*), swiss chard (*Beta vulgaris subsp. vulgaris*) and snap pea (*Pisum sativum*) to assess if such a variety and amount could be grown from the target nutrient solution.

It was hypothesized that the plants would be able to grow in size and foliage in this system, though possibly with some signs of nutrient deficiencies, since it was not clear that all necessary macro and micronutrients would be soluble and plant available even after an aerobic treatment with the MBBR. It was also unclear if the weekly amount of green waste biogas slurry added would be enough for the amount of plants, the type of plants, and their full growth.

The results from this proof-of-concept can enable future applications, since biogas production from organic waste is being expanded in many countries, creating more slurry waste whose nutrients can be recycled back into plant growth in a safe way. Additionally, such a nutrient solution would prove more sustainable in its nutrient sourcing compared to traditional mineral solutions. and such use for the slurry as a hydroponics solution would highlight the advantages of hydroponic cultivation, such as faster growth and reduced water use. Lastly, a clear path from organic waste to a sustainable nutrient source would be mapped in the soilless agricultural industry.

2. Materials & Methods

The experiment took place at the office of a Swedish Non-governmental organization (NGO) formerly located in the Augustenborg neighborhood, in Malmö, Sweden, with the goal of teaching hydroponic and aquaponic concepts. The experimental set-up specifically was located in the basement of the office without any source of natural light.

The proof-of-concept was designed out of existing materials provided at the office. An overview of the system can be seen in Figure 1. The nutrient film technique (NFT) component consisted of four Zipgrow™ towers from Bright Agrotech. The towers include a matrix media inside where seedlings are placed, made from recycled PET-1. The towers were slanted at 22.5º-45º to ensure a gravity flow of water. The water exiting the towers was collected with a plastic gutter that funneled it with the help of a bulkhead fitting and a funnel to the MBBR system below. The water piping system was made from a 13 mm LDPE hose. The MBBR consisted of a 25 L HDPE plastic canister with the top cut off for ease of access. Inside, a submersible pump (Hailea HX 2500) was placed and connected to the LDPE hose. The inside of the 25 L HDPE plastic canister was also filled at 50% with K1 carriers from online supplier Dammbutiken (Diameter: 11mm, Height: 7mm, Total surface area: 850 m^2/m^3,Protected surface area: 500 m^2/m^3). Finally, an air pump (Hailea IPX1 ACO-9601) was placed outside, with its outgoing air directed via a 19 mm rubber hose inside the MBBR, for continuous mixing of the K1 carriers. Both the air pump and the water pump operated continuously throughout the experiment, without any timers. Above the towers was a fixture with fluorescent lights OSRAM LumiLux Cool Daylight HO 80W/865 operating during 13 hours per day with a PAR level between 50-150 mol m^{-2} s^{-1}, for optimal plant growth, covering roughly all the length of the tower.

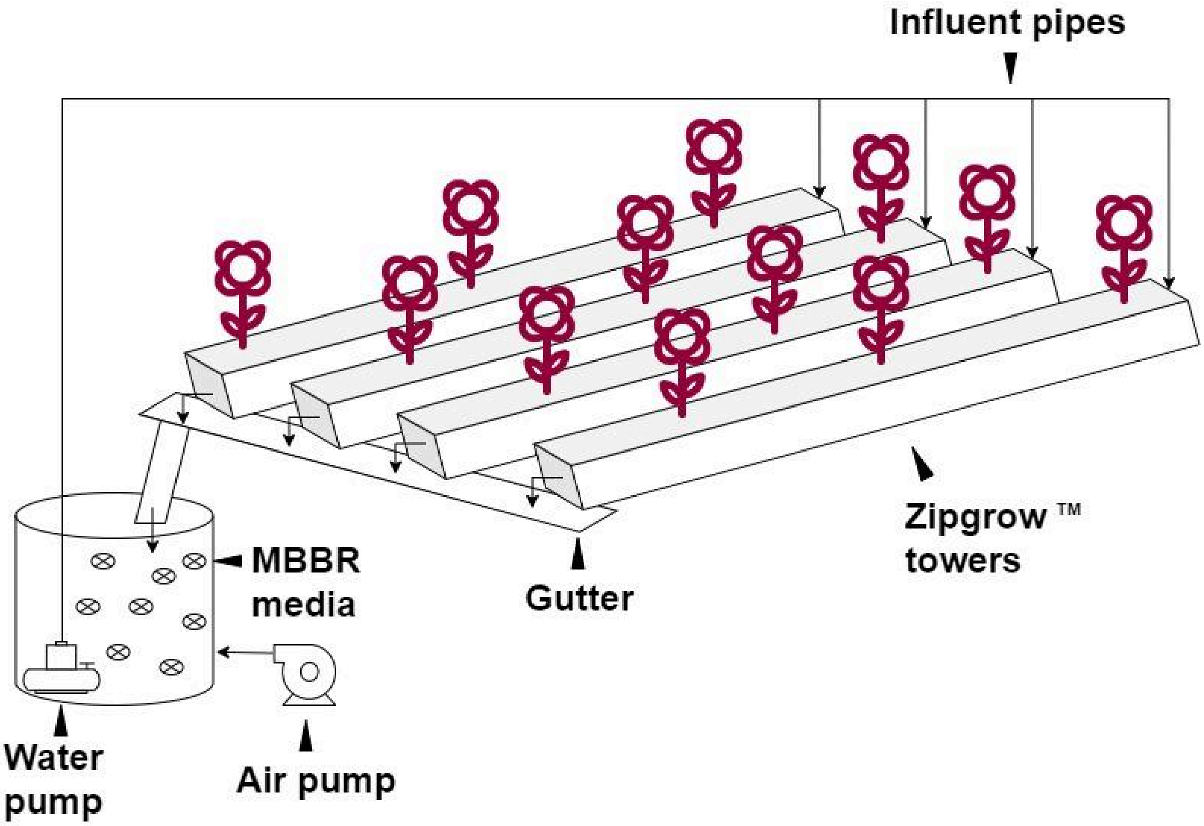

Figure 1: Proof-of-concept overview showing the MBBR, pumps, towers, plants, and water flow.

Unfortunately, little information was available at the time of writing of this report regarding the details of the green waste biogas slurry solution. The initial slurry came from a biogas plant in Helsingborg which took municipal green waste and produced biogas as well as "biocompost" for agricultural use. Upon receiving the slurry, the same was centrifuged to achieve maximum solid separation, and the supernatant was collected and stored in the fridge until its weekly use while the separated solids were placed in the office's vermicompost.

It was calculated that beginning with a weekly dosing of 200 mL of the green waste biogas slurry supernatant would be enough, with additional chemical analysis performed to monitor the development over time. A 200 mL/week would correspond to a daily addition of 28.57 mL/day. The weekly dilution factor was 1:125, although this was reduced to 1:41 later. The slurry was added weekly due to the logistics of the NGO routines.

pH and EC were measured almost weekly throughout the experiment with HM Digital PH-80 and HM Digital COM-80 meters respectively. These two parameters were measured as they are the standard parameters measured in hydroponic solutions. EC, or electrical conductivity, is an indication of the number of nutrient salts available for plant uptake in a solution, and the pH indicates how such nutrient salts may be more available or not by the plant. Additionally, four filtered samples were collected throughout the experiment (two hours after slurry addition) and analyzed with Hach Lange test kits for sCOD, NH4-N, NO3-N,

NO_2-N, and PO_4-P, providing information on the evolution of some nutrients and compounds.

The plants added were *Basil Emily Batch N* from Nelson Garden, *Lettuce Lollo Rossa Batch AV* from Nelson Garden, *Swiss Chard Fantasy F1 Hybrid* from Thompson&Morgan, and *Bytsockerärt "Tom Thumb"* from Impecta Fröhandel, and were sowed in sponge-cubes in a flood and drain tray using Nelson Garden "hydroponisk näring" one-part solution as the nutrient solution (total EC = 0,6 mS/cm). Once the seedlings had at least a second pair of leaves, they were moved into the NFT system and the experiment began.

3. Results

While the experiment was set up and running during a period of 90 days, building a nitrifying bacterial colony and adjusting water flows, it was only during 60 of those days that plants were fed the green waste biogas slurry. In that time, it was possible to observe continuous growth and development of the seedlings into fully grown plants. The overall progress can be seen in Figure 2.

The system began with a weekly addition of 200 mL of centrifuged slurry supernatant on March 7th 2019, which was increased to 400 mL/week on April 24th 2019, and finally to 600 mL/week on May 1st 2019.

Figure 2: First towers added with snap peas and lettuce on April 3rd 2019 (top left image), swiss chard tower added replacing the previous snap pea tower, and basil tower added on April 10th 2019 (top right image), adding the snap pea tower on May 1st 2019 (bottom left image), and the last day without flow issues on May 22nd 2019 (bottom right).

The operation of the experiment was met with some difficulties, namely the appearance of aphids (*Aphidoidea*) and the disruption of normal flow operation due to piping clogging, flooding around the experiment area, and subsequent water volume loss. In Table 1 the several disruptions are listed by chronological order.

Table 1: Disruptions and actions performed during the 90 days of the experiment, detailing pests and water losses.

Date (dd/mm/yyyy)	Disruption and action performed
13/3/2019	Tower feed tubes changed for increased diameter given clogging due to solids.
20/03/2019	NFT tower inclination raised due to minor flooding.
27/03/2019	Aphids found in many seedlings, which were subsequently submerged in chemical diluted solution for pest management (Monterey Garden Insect Spray, 15 mL/L).
03/04/2019	Continued aphid management in seedlings. Aphids found in towers were sprayed with diluted neem oil on affected plants.
10/04/2019	Snap peas seedlings were growing poorly due to aphids and chemical treatment, snap pea tower was replaced with a basil tower, and a new tower with swiss chard was added. Fighting aphids in the seedling tray and in towers continued.
17/4/2019	Seedling tray seedlings found dead due to pump issues, thereby losing snap pea seedlings. Tubing to the pump was fixed, and snap peas were seeded again. Tray was also cleaned.
26/04/2019	Minor issues with the water pump and the water flow stopping.
01/05/2019	Aphids found in basil, sprayed Pyretrin diluted with water.
08/05/2019	Some water leak issues upon arrival (MBBR almost empty) but there was still water flowing. Aphid management continued in the basil plants.
09/05/2019	Big water leak in system, system was restarted but the plants were wilted.
15/05/2019	Continuing aphid management in basil plants.
18/05/2019	Big water leak in system, system restarted but the plants were wilted, especially the lettuce.
22/05/2019	Continuing aphid management in basil plants.
29/05/2019	Another leak affecting mostly lettuce plants. The experiment ended.

On March 27th 2019 the first signs of aphid infestation began to appear on the seedlings prior to their transplant to the towers. It is believed that the aphids originated from outside contamination, as they were placed near the entrance door of the office. By April, aphids were visible in some plants (Figure 3), and at the same time, water loss was occurring due to the matrix media inside the towers becoming blocked with solids, leading to water exiting through the top of the tower (Figure 3).

Figure 3: Aphids (white circle) on a snap pea plant on April 10th 2019 (left image), and inlet water flow escaping the top of a tower due to matrix media clogging (right image), on April 17th 2019.

The aphids were managed using three methods: a spinosad solution, neem oil, and Pyretrin. The first method used Monterey Garden Insect Spray, a spinosad containing solution for control of foliage feeding pests. The solution was mixed at a concentration of 15 mL/L and each seedling was individually submerged in the final solution. Later, the initial Monterey solution was mixed with Neem oil in a similar concentration and also by submersion. Lastly, after insufficient pest control from the previous solutions, a mix of water and Pyretrin at a concentration of 2% seemed to substantially reduce the number of aphids.

Regarding water flow issues, as the matrix media would become filled with plant roots and solids from the slurry, and considering the unconventional use of the towers in a partially tilted mode (they were designed for a 100% vertical application), eventually the water flow would become disrupted in such a way that it would start exiting from the top of the tower rather than reaching the plant's roots, leading to underwatering and plant wilting (Figure 4).

Figure 4: Normal plant growth on May 13th 2019 (left image), and wilted plants due to flow issues and underwatering on May 18th 2019 (right image).

The regular measurements taken showed an initial decline of pH with a slow rise over time, while EC remained constant with a spike towards the end of the experiment (Figure 5).

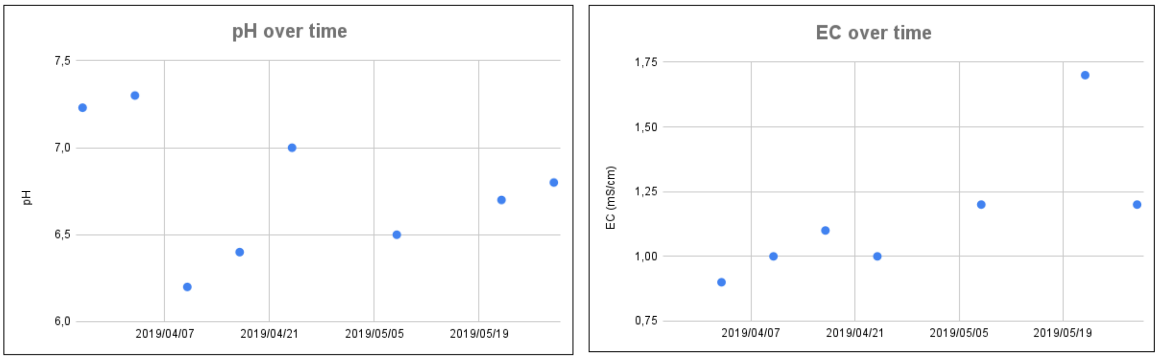

Figure 5: Variation of pH (left image) and EC (right image) during 60 days of operation, between March 27th and May 29th 2019.

The other parameters measured can be seen in Table 2. These showed an increase in all parameters except nitrate nitrogen.

Table 2: Concentrations of soluble chemical oxygen demand, ammonium nitrogen, nitrate nitrogen, nitrite nitrogen, and orthophosphate phosphorus in four instances roughly two weeks apart.

Date (dd/mm/yyyy)	Soluble COD (mg/L)	NH4-N (mg/L)	NO3-N (mg/L)	NO2-N (mg/L)	PO4-P (mg/L)
27/03/2019	329,60	19,50	31,51	0,27	5,96
17/04/2019	344,00	20,62	62,39	0,01	10,21
01/05/2019	-	-	4,9	-	-
22/05/2019	1 117,00	98,50	31,40	1,4	14,70

At the end of the experiment, the swiss chard, lettuce, and basil had grown to a full harvest size, and the snap pea plants had all fruited pods and were also ready for harvest, though a more modest one by comparison.

4. Discussion

It is believed that both the aphids and the flow issues resulted in the difficult start-up of the experiment . However, once these issues were resolved, plant growth performed similarly to what would be expected in a mineral hydroponics system.

It is possible that the increase in EC and other parameters like sCOD, NH_4-N, NO_2-N, and PO_4-P, indicate an imbalance in the system that would result in sub-optimal growth or plant death given a longer runtime. However, the number of samples performed was very reduced due to limited resources available, so future experiments should follow the concentrations more frequently, perhaps daily, and at different stages of slurry addition.

In conclusion, this proof-of-concept shows that a nutrient film technique hydroponics system has potential for the production of a variety of crops using the supernatant of a green waste biogas slurry as the nutrient solution.

Further experiments could explore possibilities to optimize the growing process and account for uncertainties by considering the following ideas:

- Setting the experiment with an NFT system without a matrix media, or alternatively, using the towers vertically as the ones used in this experiment were originally designed to be used as.
- Creating a more protected environment from pests such as aphids.
- Confirming the results with a greater number of plants, and with simultaneous control groups, both in regular water and using mineral hydroponic solutions.
- Attempting a pure passive approach, or Kratky, without the use of a MBBR, air pump and plastic media.
- Trying different amounts of slurry supernatant in different concentrations and water volumes, with an even wider variety of plants.
- Using different sources of green waste biogas slurry from different variations of organic waste to potentially create recipes for different plant stages.

5. References

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