Lactuca sativa production in an Anthroponics system

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Abstract

Anthroponics is a recirculating soilless agriculture system that uses natural bacterial cycles to convert human biowaste into plant fertilizer. In this investigation the concept of anthroponics and the underlying processes are explained, and an overview on the existing knowledge of urine and anthroponics systems is also presented.

A small experiment was conducted in Malmö, Sweden. The method involved building three anthroponic systems and collecting urine samples from one healthy individual. The objective was to calculate an average and median time for urine volatilization to ammonia, and to cultivate *Lactuca sativa* in the anthroponic systems under different dosages of urine. The systems were tested for Total Ammonia Nitrogen (NH_4^+/NH_3), Nitrite (NO_2^-), Nitrate (NO_3^-), Electrical Conductivity (EC) and pH.

The first batch of urine had an average volatilization time of 4,7 weeks and a median volatilization time of 5 weeks. The second batch of urine had an average volatilization time of 4,7 weeks and a median volatilization time of 4 weeks. The third batch of urine had an average volatilization time of 4 weeks and a median volatilization time of 2 weeks. For the anthroponic systems, the aged urine used to cycle the systems and create the bacterial colony was sufficient to grow all of the crops from seedling to harvest, thus diverging from the original protocol. Each system used 100mL of aged urine during a total period of 35 days: System 1 produced 225g of lettuce, System 2 produced 221g of lettuce, and System 3 produced 180g of lettuce.

In conclusion, the average amount of urine produced by an adult human per day can grow around 3kg of lettuce. Current requirements for ageing urine for safe anthroponic use take a long time for any scalable solution in agriculture or wastewater treatment. Better measuring techniques, longer testing periods and more research is recommended in this field in order to draw an improved representative conclusion.

Keywords: Anthroponics, aquaponics, human urine, hydroponics, nutrient recovery, wastewater treatment.

Contents

1. Introduction

1.1. Definition

Anthroponics can be defined as a recirculating soilless agriculture system that uses natural bacterial cycles to convert human biowaste into plant fertilizer. The name is a compound of Greek ἄνθρωπος anthrōpos, or "human being" and hydroponics. Anthroponic systems will typically combine aspects of aquaponic farming, organic hydroponics, and wastewater treatment.

Aquaponics can be defined as “The cultivation of fish and plants together in a constructed, recirculating ecosystem utilizing natural bacterial cycles to convert fish waste to plant nutrients. This is an environmentally friendly, natural food-growing method that harnesses the best attributes of aquaculture and hydroponics without the need to discard any water or filtrate or add chemical fertilizers” (Bernstein, 2013). In this context, aquaculture refers to the farming of aquatic organisms with human intervention to improve production (FAO[1] , 2014). On the other hand, hydroponics refers to growing plants without soil, where the nutrient source is either a nutrient solution or nutrient enriched water (Jones, 2005).

An anthroponic system can be supported on only human urine, and theoretically human feces through the use of an aquaponics subsystem. It may also be possible to use both urine and feces in combination. In this experiment, human urine anthroponic systems were built.

1.2. Objectives

One of the objectives of the experiment is to investigate the average and median time it takes for urine to reach a pH of 9, and therefore be regarded as safe to use in anthroponic systems. Another objective is to conduct a two-phase experiment with three equal anthroponic systems. Here the dosage required to cycle the systems (I.e. to build the nitrifying bacterial colony) will be determined, as well as monitoring each system under different urine dosaging both in chemical analysis (EC, pH, NH_3/NH_4^+, NO_2, NO_3) and crop weight after harvest. The systems will be built at Hemmaodlat’s office. Hemmaodlat is a Swedish NGO organization located in Malmö, Sweden, with the goal of teaching hydroponic and aquaponic concepts.

It is expected that the knowledge gathered will enable further experiments with a better confidence in the design, dimensioning of anthroponic systems, the dosage amounts, and the different system component ratios.

1.3. Fundamentals

There is little research done on the topic of anthroponic systems. The only academic document available is the master thesis *Aquaponics and its potential aquaculture wastewater treatment and human urine treatment* (Sanchez, 2014). There a detailed construction of an anthroponic system using human urine is described, however no in depth design and dosage guidelines were presented.

Aleece Landis is a known member of the Backyard Aquaponics community, and she was one of the first people performing regular testing and documentation of an

anthroponic system (known as “peeponics”). Her system was based on a Barrel-ponics® design with urine, using a similar methodology described by the above master thesis. Landis’ results will be used as a starting point for this investigation. Her system specifications are specified below in Table 1, as well as the calculated values per liter of biofilter volume.

Table 1: Landis’ Anthroponic System as documented in Backyard Aquaponics and calculated values per liter of biofilter media volume.

	Aged Urine (mL/day)	**Biofilter Media Volume (L)**	**Total System Water Volume (L)**	**Growing Area (m^2)**
Landis’ System	200	250	283 - 378	0,67
Calculated Values	0,8	1	1,13	-

Human urine, the main nutrient source of this anthroponics experiment, is an aqueous solution secreted by the kidneys which consists primarily of water. Remaining main components include urea and dissolved ions such as chloride, sodium, potassium, and creatinine (Putnam, 1971). Urine can provide a plant-available source of nitrogen by a process known as ammonia volatilization from urea. In this process, urease catalyzes the hydrolysis of urea to unstable carbamic acid, followed by a rapid decomposition of carbamic acid to form un-ionized ammonia (NH_3) and carbon dioxide (Tisdale *et al*, 1985). The above description can be expressed as the following chemical reaction:

$$(NH_2)_2CO + H_2O \xrightarrow{\text{urease}} NH_3 + H_2NCOOH \rightarrow 2NH_3\,(gas) + CO_2\,(gas)$$

The formed ammonia might escape to the atmosphere unless it reacts with water to produce ionized ammonia (NH_4^+), according to the following reaction:

$$NH_3(gas) + H_2O \rightarrow NH_4^+ + OH^-$$

This reaction is important to note since ionized ammonia is a plant available source of nitrogen while un-ionized ammonia is not (Brady & Weil, 2001).

Urine is generally considered a fertilizer, and suitable for anthroponic use only when it is acquired from a healthy individual without any current illness or infection and under no type of medication.

As with aquaponics, the ammonia will now enter the nitrogen cycle of the system occurring at the biofilter level. In this cycle, nitrogen takes three main forms: ammonia (NH_4^+ or NH_3), nitrite (NO_2) and nitrate (NO_3). An explanation of the nitrogen cycle is proposed by Tyson *et al* in their 2004 *Reconciling water quality parameters impacting nitrification in aquaponics: The pH levels* scientific paper: “Ammonia is the main excretion product from fish. Both un-ionized ammonia and nitrite can be toxic to fish at very low levels. In the process of nitrification, certain autotrophic bacteria (primarily *Nitrosomona*) oxidize ammonia to nitrite and others (primarily *Nitrobacter*) oxidize nitrite to nitrate. The overall reaction of nitrification and cell biomass formation can be written as:

Nitrosomonas

$$55\,NH_4^+ + 5\,CO_2 + 76\,O_2 \rightarrow C_5H_7NO_2 + 54\,NO_2^- + 52\,H_2O + 109\,H^+$$

Nitrobacter

$$400\ NO_2^- + 5\ CO_2 + NH_4^+ + 195\ O_2 + 2H_2O \rightarrow C_5H_7NO_2 + 400\ NO_3^- + H^+$$

The nitrogen transformation eliminates ammonia from the water. Nitrate (…) is the primary source of nitrogen for plants in hydroponic systems".

In aquaponic online communities there is no standard name for this sort of practice, although common terms found online include "urineponics", "peeponics", and "bioponics". In these communities, some of the testimonies and experiments shared present a methodology that seems to be based on the research conducted by Pradhan *et al* on the use of urine as a plant-fertilizer. According to their methods, urine is first aged to kill any possible hazardous pathogens that may contaminate the produce. Sterilizing the urine helps minimize the risk of any possible health problem, since it leads to very few detected microorganisms such as fæcal coliforms, clostridia, enterococci and coliphages (Pradhan *et al*, 2007).

There is mixed research suggesting that urine is sterile until it reaches the urethra (Madigan & Brock, 2009), while other suggests that urine is not sterile even in the bladder (Hilt *et al*, 2013). A source-separation of urine, should contemplate that the risk for transmission of disease when using urine mostly depends on cross-contamination by fæces (Höglund, 2001). Considering urine may not be sterile, bacterial population can be reduced by allowing the urea to be degraded by the urease enzyme to ammonium and water. It has been observed that allowing the urine to degrade until it reached a pH level exceeding 9 will result in bacterial reduction (Pradhan *et al*, 2007). Recommended storage time is 6 months for the use of urine as fertilizer in soil in colder climates (Jönsson *et al*, 1997), however it should be sufficient to wait until the target pH level has been reached.

2. Anthroponics experiment

2.1. Methodology

2.1.1. Collecting and measuring urine pH

Urine collection was done in three batches, each having three different jars with the same volume. Each batch had different volumes: the first batch having 100mL, the second batch having 300mL, and the third batch having 400mL (Table 2).

Table 2: Urine collection arrangement with volumes, jar numbers and batch numbers.

Jar number/ Batch number	Volume (mL)
Jar 1/ Batch 1	100
Jar 2/ Batch 1	100
Jar 3/ Batch 1	100
Jar I/ Batch 2	300
Jar II/ Batch 2	300
Jar III/ Batch 2	300
Jar IV/ Batch 3	400
Jar V/ Batch 3	400
Jar VI/ Batch 3	400

The urine was collected from the same individual who was healthy and under no medications. To prevent collecting any solids that may be in the urethra, the urine was collected after the first few seconds or urination and each jar was closed as soon as the target volume was collected. In the first batch, with each one of the three jars having 100mL, the urine collected came from the same urination. In the second batch, the urine collected came from the same urination, with each one of the three jars having 300mL. In the third batch, the urine collected came from two different days, with less than three days difference between them.

The pH of the urine was measured through an electronic pH meter (Figure 1). The pH value on the meter was always allowed time to stablize.

Figure 1: HM Digital waterproof PH-200 used for measuring the pH of the collected urine.

The pH of the jars was measured weekly or at different set times, depending if the urine was collected during the same urination or at different days. If the urine was collected during the same urination, each jar would be opened and its pH measured with a week of difference between the jars (batch 1 & 2). If the urine was collected at different times in the batch, then each jar would be opened and have its measured every week until the target pH was achieved (batch 3).

2.1.2. Chemical analysis

Test kit solutions that were available and affordable for the project budget included TAN or Total Ammonia Nitrogen (NH_4^+/ NH_3), Nitrite (NO_2^-) and Nitrate (NO_3^-), conducted through commercial aquarium test kits (Figure 2).

Figure 2: From left to right: JBL test kits for Ammonium/Ammonia, Nitrite and Nitrate.

The commercial test kits for TAN, Nitrite and Nitrate are from the JBL company. All tests rely on titration methods with a colorimetric analysis, however the company were unable to give out information regarding reagents used in their test kits.

In particular, measurement of TAN and Nitrite was conducted only through the cycling process, whereas the measurement of Nitrate was conducted at the end of the cycling process and afterwards. There was also a measurement of the electrical conductivity (EC) of the water through a digital meter after the cycling process. The meter used was a digital meter for EC, TDS and Temperature (Figure 3).

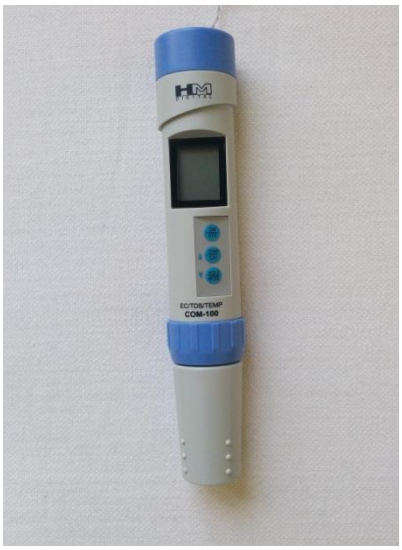

Figure 3: HM Digital waterproof COM-100 used for measuring the EC of the systems' water.

2.1.3. Dimensioning calculations

The first system (System 1) will operate under Landis' values and will serve as the control system with 4 plants. The second system (System 2) will have half as much urine dosing (7,8 mL/day). The third system (System 3) will have double the urine dosing as the first system (31,2 mL/day). Below follows a table (Table 3) with the ratios used in each of the system:

Table 3: Experiment parameters for each system

	Aged Urine (mL/day)	Biofilter Media Volume (L)	Total System Water Volume (L)	Growing Area (m^2)	Number of plants in grow box
System 1 (control)	15,6	19,5	22	0,11	4
System 2	7,8	19,5	22	0,11	4
System 3	31,2	19,5	22	0,11	4

Below a figure of the three systems is presented (Figure 4).

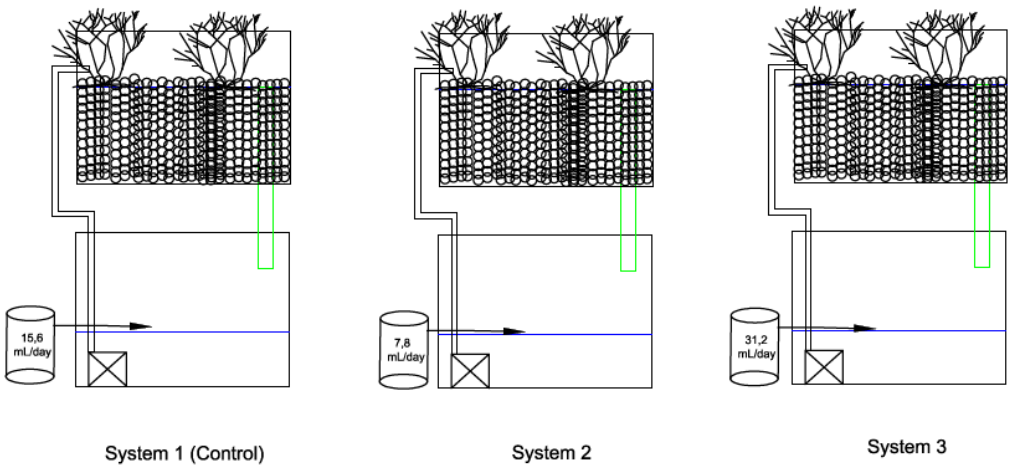

Figure 4: Experiment overview with the different systems.

All systems will be filled with Gold Label Hydrocorn, a growing medium commonly used in Hemmaodlat. This type of light expanded clay aggregate has a specific surface area (SSA) of 1250 m^2/m^3 (Albuquerque *et al*, 2009). Considering the volume of biofilter in use (19,5 L = 0,0195 m^3), this amounts to a biological surface area (BSA) of 24,37 m^2. Using Bright Agrotech's information on BSA (Michael, 2013), it is claimed that a system must have at minimum 2,5 ft^2/gallon of water, with a recommended ratio of 10 ft^2/gallon of water. According to these ratios, and converting the systems' values to the Standard System (24,37 m^2 = 262,3 ft^2 and 22 L = 5,8 gallons), the systems have a BSA of 45 ft^2/gallon of water, which is far above the minimum and recommended values, and should guarantee more than adequate biofiltration. However, a more common SSA value for light expanded clay aggregate is of 250-300 m^2/m^3 (FAO, 2014). According to this SSA, the result is a BSA of 0,0195 x 250 = 4,875 m^2 (or 52,47 ft^2). Thus each

system has a BSA of 52,47/5,8 = 9,06 ft^2 per gallon of water, which is still inside Bright Agrotech's target range.

2.1.4. Materials used and costs

The materials used were materials which Hemmaodlat has had experience in working with. In Table 4, a list of materials and their costs is shown. The costs are expressed as if all materials must be purchased and there is no possibility of re-using existing materials at Hemmaodlat.

Table 4: List and cost of materials for the experiment. Prices are from Ikea.se and Hydrogarden.se, costs are expressed in swedish crowns.

Product	Amount	Price (SEK)
SAMLA box (39x28x28) & lids	6	210
Hailea HX 2500	3	537
Gold Label Hydrocorn 45L	2	399
Plumbing components (pipes, tubings, fittings)	-	Up to 500
ROOT!T® 50st refill påse seedling medium	1	149
Light Fixtures	3	657
Total		**2452**

2.2. Construction

Three anthroponic experiment units were built during the period of about 2 months (03/03/2015 – 28/04/15) at Hemmaodlat's office. This long construction time in relation to the size of the experiment was due to other organization activities occurring at the same time and a dedication to getting the correct materials and equipment. Figures 5, 6 and 7 show the materials used and different stages of construction.

Figure 5: From left to right: The three container units with the plumbing tubes, the three light fixtures, and the three pumps, connectors, standpipes, and bulkhead fittings.

Figure 6 From left to right: Adding the bulkhead fitting & standpipe to the grow bed component, drilling the bulkhead fitting hole and pump hose in the support lid of the grow bed, and a close-up of the bulkhead fitting being inserted in the lid hole.

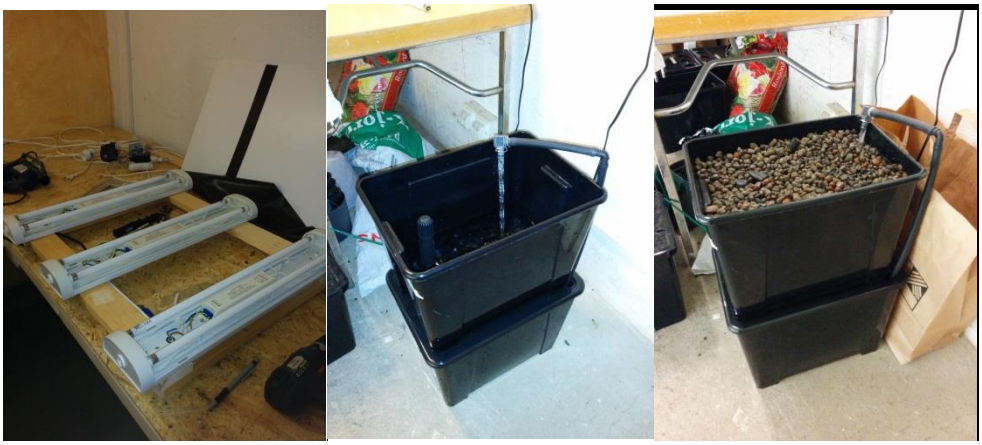

Figure 7: From left to right: Constructing the wood support for the light fixtures, testing the water flow in one of the experiment units, and testing the water flow in the same unit with the grow media (hydrocorn).

2.3. Cycling

The amount of aged urine calculated for aging was based on Sylvia Bernstein's *Aquaponic Gardening* guidelines (Bernstein, 2013), as well as information available on the concentration and composition of urine (Putnam, 1971).

According to the information on the composition of urine, it is possible to estimate that the urea is in a concentration of 0,93% (per 1L of urine). Assuming that all the urea is converted to ammonia during the volatilization process, the solution will have 0,93% of ammonia.

The reccomended dosage per day (Bernstein, 2013) is of 24,65mL for every 378,54L of fish tank volume with 10% ammonia. Since the units considered indicate a total volume of 22L, the ammount of ammonia needed would be:

$$\frac{22000\ mL\ x\ 24{,}54\ mL}{378540\ mL} = 1{,}43\ mL\ of\ 10\%\ ammonia$$

However since the available solution has a perceived percentage of ammonia of 0,93%, then:

$$\frac{1{,}43\ mL\ x\ 0{,}1}{0{,}0093} = 15{,}4\ mL\ of\ 0{,}93\%\ ammonia\ per\ day$$

As the testing *in situ* was done only weekly, the dosage amount was calculated on ~100mL (15,4 mL x 7 days), but divided by half as a precaution to not overrun the system. Thus 50mL of aged urine was added to all systems (Figure 8).

Figure 8: 50mL of aged urine, added to all three systems.

After adding the aged urine, all systems were tested for Ammonia (NH_4), Nitrite (NO_2) and (later on) Nitrate (NO_3) to monitor the cycling process and the build-up of the nitriying bacteria community (Table 5).

Table 5: Cycling measurements of Ammonia, Nitrite and Nitrate

Date	System	NH_4	NO_2	NO_3	Comments
06-05-2015	1	-	-	-	added 50mL urine
06-05-2015	2	-	-	-	added 50mL urine
06-05-2015	3	-	-	-	added 50mL urine
12-05-2015	1	<0,05	>1	-	Pump was dry, added 8L water + 25mL urine
12-05-2015	2	<0,05	0,05-0,1	-	added 8L water + 25mL urine
12-05-2015	3	<0,05	0,05	-	added 8L water + 25mL urine
19-05-2015	1	<0,05	0,025	80-160	Added 2L water + seedlings
19-05-2015	2	<0,05	0,025	80	Added 2L water + seedlings
19-05-2015	3	<0,05	0,025	80	Added 2L water + seedlings

The cycling process took an unexpectedly short time compared to reports of other aquaponic practitioners. This may have been since the media selected had been used for other hydroponic systems previously, and despite having been washed thoroughly some existing nitrifying bacteria may have survived and thrived in this new ammonia-rich environment.

After the first week of cycling, given that effective ammonia to nitrite conversion was recorded, it was decided to lower the dosage by half (from 50mL to 25mL) to not

overrun the system with eventual nitrates as there were still no plants inserted for uptaking them.

During the second week, high nitrate values were recorded, indicating a successful cycling process and running system. The seedlings were then added, with each system having the same four different subtypes of *Lactuca sativa*: *Lactuca sativa* var. *Crispum*, *Lactuca sativa* var. *Longifolia*, *Lactuca sativa* var. *Crispa*, and *Lactuca sativa* var. *Capitata crispum* (Figure 9).

Figure 9: Image of the seedlings being started in hydroponic nutrient solution and rootit cubes (6th May 2015) and the same seedlings being added on the anthroponic experiment units (19th May 2015).

3. Results

3.1. Volatilization times

The electronic pH meter was not available at the start of the initial collection of urine, and during the first few weeks only available intermittently. As such, the pH of enclosure (i.e. the fresh urine) was not available for the first and second batches.

In the first two batches, as the urine was collected from the same day in each batch, each jar from the batch was opened at measured at different times: one jar was opened and its pH measured after one week of ageing, another jar was opened and its pH measured after two weeks of ageing, and the last jar was opened and its pH measured after three weeks of ageing. Afterwards all jars were opened and their pH measured after four weeks since the initial enclosure. This enabled the confirmation that (at least for the first batch) more than three weeks is required for the urine to reach a pH of 9, with the time being closer to between four and five weeks (Tables 6 & 7).

Table 6: Batch 1 results after two and three weeks of ageing.

1st batch	Jar 1 (100mL)	Jar 2 (100mL)	Jar 3 (100mL)
Enclosure date (13:00)	18-03-2015	18-03-2015	18-03-2015
Opening date	25-03-2015	01-04-2015	08-04-2015
pH opening	-	8,4	8,5

Table 7: Batch 1 results after four weeks of ageing.

	Jar 1 (100mL)	Jar 2 (100mL)	Jar 3 (100mL)
4th week (15-04-2015) pH results	9,1	8,8	8,7

This first batch was measured to get an idea of the timeframe as the baseline for future measurements, and also to cycle the anthroponics experiment units. The second batch was conducted with the same methodology as Batch 1 (Tables 8 & 9), though one jar took considerably longer than others.

Table 8: Batch 2 results after two and three weeks of ageing.

1st batch	Jar I (300mL)	Jar II (300mL)	Jar III (300mL)
Enclosure date (21:00)	04-06-2015	04-06-2015	04-06-2015
Opening date	11-06-2015	18-06-2015	25-06-2015
pH opening	7,12	8,07	6,65

Table 9: Batch 2 results after four and six weeks of ageing.

	Jar I (100mL)	Jar II (100mL)	Jar III (100mL)
4th week (02-07-2015) pH results	9,58	9,08	7,13
6th week (16-07-2015) pH results	-	-	9,43

In Batch 3, the urine in each jar came from different urinations at either different times during the day (Jars V and VI) or different days (Jar IV). Results from Batch 3 are presented in Table 10.

Table 10: Batch 3 results after two and eight weeks of ageing

	Jar IV (400mL)	Jar V (400mL)	Jar VI (400mL)
Enclosure date	12-06-2015	15-06-2015	15-06-2015
pH enclosure	6,05	6,69	6,14
Week 1 pH results	6,45	8,48	7,87
Week 2 pH results	6,82	9,53	9,5
Week 3 pH results	-	-	-
Week 4 pH results	7,14	-	-
Week 5 pH results	7,64	-	-
Week 6 pH results	8,16	-	-
Week 7 pH results	8,75	-	-
Week 8 pH results	9,28		
Time to reach a pH of 9 (weeks)	8	2	2

3.2. Crop growth

As described in the objectives of this investigation, the initial goal was to research the amount of urine to cycle the anthroponic systems, as well as test different urine doses. However the growth of the different subspecies of *Lactuca sativa* was quicker than expected, which resulted in ready-to-harvest crops with the amount of urine necessary to cycle the systems and a small compensation amount (Figure 10).

Figure 10: Image of the evolution of the lettuce in the anthroponicsexperiment units using the aged urine from the cycling process. From left to right, the dates are: 20th May 2015, 2nd June 2015, 10th June 2015, and 23rd June 2015.

The amount of lettuce harvested totaled 626 grams (Figure 11) in the time frame of 33 days using 100mL per system.

Figure 11: Lettuce harvested per system, totalling 626g. 23rd June 2015.

While the root development appeared normal after the harvest (Figure 12), some minor abnormalities were observed. These include leaf discoloration, some necrosis spots, and the buildup of salts on the surface of the grow media (Figure 13).

Figure 12: From left to right: root development in System 3, System 2 and System 1. 23rd June 2015.

Figure 13: From left to right: Leaf discoloration in a plant of System 3 (16th June 2015), necrosis spots in a plant of System 1 (16th June 2016), and salt buildup in the hydrocorn surface of System 1 (23rd June 2015).

Table 11 shows the different paraments tested after the system was cycled, and the results obtained during the time period 2nd June 2015 - 23rd June 2015.

Table 11: Nitrate, EC and pH measurement in preparation for the dosage experiment.

Date	System	NO_3 (mg/L)	EC (µS)	pH	Comments
02-06-2015	1	40-80	0,78	7,88	Added 4L water
02-06-2015	2	20-40	0,81	7,87	Added 4L water
02-06-2015	3	40	0,61	7,91	Added 4L water
10-06-2015	1	10-20	0,97	8,2	Added 8L water
10-06-2015	2	5-10	0,7	8,07	-
10-06-2015	3	5	0,56	8,14	-
16-06-2015	1	<0,05	0,77	8,41	Added 25mL urine + 2L water
16-06-2015	2	<0,05	0,76	8,27	Added 25mL urine + 2L water
16-06-2015	3	<0,05	0,64	8,39	Added 25mL urine + 2L water
23-06-2015	1	-	-	-	Harvested 225g salad
23-06-2015	2	-	-	-	Harvested 221g salad
23-06-2015	3	-	-	-	Harvested 180g salad

4. Discussion and conclusions

In regards to the first experiment it should be considered that urine is a very complex solution, and changes in the environment as well as diet greatly affect all its composition. It is also likely that even collecting urine from the same urination event in different jars might lead to different chemical properties and different volatilization times. This effect can be seen in Figure 14, where the results of four jars with consecutive pH measurements were plotted.

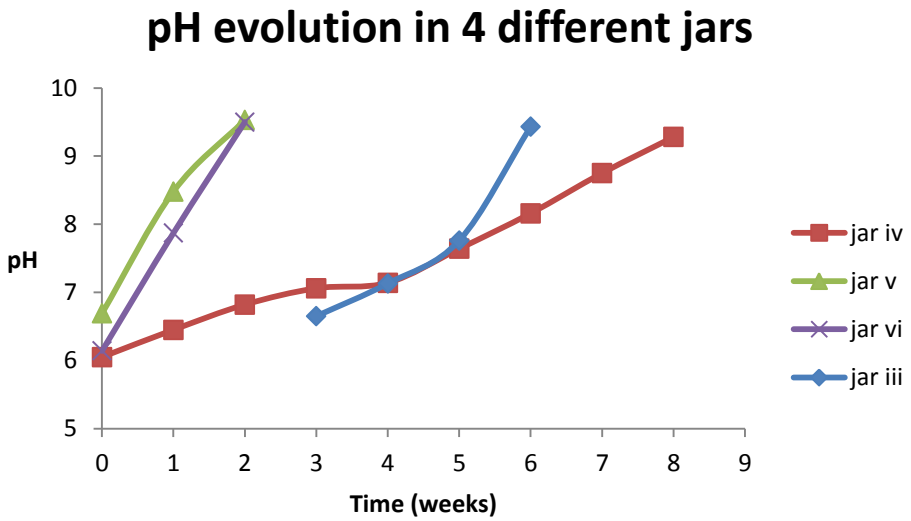

Figure 14: Evolution of pH in four jars with consecutive pH measurements, until a pH of 9 was reached.

The results show that in order to expect urine with pH over 9 will require a storage time of minimum five weeks, although a storage of six weeks is recommended. The results from this first part of the investigation are shown in Table 12.

Table 12: Average and Median volatilization time, in weeks, for the different batches of urine tested.

	Batch 1	Batch 2	Batch 3
Average volatilization time (weeks)	4,7	4,7	4,0
Median volatilization time (weeks)	5,0	4,0	2,0

In the second part of the investigation, it is seen that the initial amount of urine used for cycling was too much for the system size and the plants used. This is supported by Nitrate levels only reaching minimum levels after a month after the last urine dosage for the cycling stage (12th of May 2015). This is why it was decided to add another 25mL of urine to all systems on the 16th June 2015 to maintain the system, and to harvest the plants the following week.

A possible explanation to the miscalculation in dosaging the urine for the cycling stage might be due to the chemical reaction of ammonia volatilization from urea, presented in chapter 1.3. (Brady & Weil, 2001):

$$(NH_2)_2CO + H_2O \xrightarrow{urease} NH_3 + H_2NCOOH \rightarrow 2NH_3\,(gas) + CO_2\,(gas)$$

In section 2.3. (Cycling) it was assumed that all urea was transformed to ammonia at a 1:1 ratio. However the above chemical reaction states otherwise, correcting the ratio to 1:2. While the dosage amount calculated for cycling was halved as a precaution (from 100mL to 50mL), it seems the amount being dosed was still not accurate.

Overall the experiment with the anthroponic systems built went relatively well, and have allowed for interesting data collection. The main parameters and results are presented in Table 13.

Table 13: Main parameters and results of production in the experimental anthroponic systems.

System	1	2	3
Total Water volume (L)	20-25	20-25	20-25
Pump flow rate (L/h)	650	650	650
SSA media (m^2/m^3)	250	250	250
Biofilter volume (L)	19,5	19,5	19,5
BSA (m^2)	4,875	4,875	4,875
Total aged urine added (mL)	100	100	100
Time period seedling-harvest (days)	35	35	35
Plant growing area (m^2)	0,11	0,11	0,11
Number of plants in grow box	4	4	4
Plant species	*Lactuca sativa*	*Lactuca sativa*	*Lactuca sativa*
Total harvested plant weight (grams)	225	221	180

This experiment has been able to show that a considerable amount of *Lactuca sativa* can be grown from a very small amount of urine using simple and inexpensive systems. Based on these results it takes on average 0,47 mL of urine to grow 1g of lettuce, though differences in the subspecies of lettuce and the individual's urine may significantly alter this proportion.

Considering this proportion and that on average an adult human produces around 1,4L of urine per day (Rose *et al*, 2015), one adult could potentially produce almost 3kg of lettuce from one day's worth of urine.

5. Future research

As the original objective for this investigation was not possible, future research will focus on testing different urine dosages. Cultivating a different crop, one more nutrient demanding and also more sensitive to potential nutrient defficiencies might be interesting as well. A tomato plant or a cucumber plant might be used in this regard, as they are fruiting plants and require more nutrients than lettuce.

Future research should also attempt to test the bacterial properties of the aged urine before being added to an anthroponics system and after being added to such system. Access to laboratory tools is essential to be able to better study the chemical and bacterial properties of anthroponics systems.

Building anthroponics systems that are more automated in their handling of urine could allow for better integration into existing urine-separated toilets, thus allowing for the local treatment and reuse of the urine.

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