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Human Liquid Bio-Waste, as an Alternative Source of Fertilizer in Urban Indoor Agriculture

Analysis of Swiss Chard Growth in Vertical Farming System

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ABSTRACT

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Human Liquid Bio-Waste, as an Alternative Source of Fertilizer in Urban Indoor Agriculture
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The purpose of this thesis was to determine whether human urine in the form of urine concentrate has the potential to replace chemical fertilizers used in agriculture. This was done by growing swiss chard plant in a vertical farming system. The role of biochar was also studied to compare the difference in growth if mixed with the growing substrate.

This study was carried out as a research project between Tampere University of Applied Sciences and Evergreen Farm Oy company. It was funded by The Ministry of Agriculture and Forestry of Finland. The project was executed in a vertical farming system called Grow360™ in the premises of the company. The system has 15 vertical cylinders, each containing 144 buckets for plants totaling up to 2160 plants which acquires an area of 9 m^2 with 2.5 m height. This system was installed and customized according to the project specifications with 8 different combinations of nutrition treatments. Quantitative data were collected in the monitoring phase of swiss chard growth for 10 weeks after sowing until harvesting and was analyzed and compared for growth results.

The results showed that the plants treated with urine concentrate had slow growth in the start compared with the ones treated with chemical fertilizers. However, by the end of growth week 10 they grew more in length. The average growth of urine concentrate treated plants were 21.72 cm and chemical fertilizer treated plants were 20.85 cm. It was found out that treatments with lower nitrogen concentration with 100 mg/L yielded better growth than higher nitrogen concentration with 150 mg/L. The results also showed that plants with biochar mixed in the medium had better growth than the plants with only peat as a growing media.

The findings indicated that the urine concentrate with the lower nitrogen level has the potential as an alternative to the conventional chemical fertilizer used in agriculture. Biochar addition to the growing substrate yields better growth and produce. The Grow360™ unit was a prototype system with limited automation and lower technology readiness level. It would be recommendable to conduct similar research in a completed system with full automation. Furthermore, other growing factors like soil pH, electrical conductivity and manpower for sowing and harvesting is to be well planned before the project's execution for more synchronized, comparable and reliable results.

Key words: urine, fertilizer, vertical, farm, agriculture, swiss chard, nitrogen

CONTENTS

GLOSSARY

TAMK	Tampere University of Applied Sciences
UC	Urine Concentrate
DFVH	Direct Feed Vertical Hydroponic
EC	Electrical Conductivity
Yara A	Ferticare 4-17-24
Yara B	Yara Calcinit

1 INTRODUCTION

It is estimated that according to the current growth rate, the population will increase up to 9,6 billion in 2050. Hunger alone is taking more lives than people suffering from diseases like malaria, AIDS and tuberculosis combined. Global food stability and security is threatened by the factors like rising prices, climate disasters, arable land shortage, drought, political instabilities and increasing food demands. Analyses by Food and Agriculture Organization (FAO 2009) shows that the overall food production must be increased by 70% from 2009 levels by 2050. Experts also predict that it will require five times the earth's total resources to satisfy the demands of a world population that eats at a rate equal to that of the United States currently (Population connection 2015).

One of the solutions to the many challenges that the world is facing right now lies in agricultural production boost, keeping the mindset of a circular economy. Vertical farming has that potential to help solve this challenge. A key factor in crop production is the need of fertilizers and to make it a sustainable choice, human urine may have the potential for a sustainable vertical farming solution as it contains N (nitrogen) and P (phosphorus) which are two of the major nutrients that plants require.

This experiment aims to find out whether the human liquid bio-waste has a safe and sustainable potential to replace conventional fertilizers in food and agriculture by analyzing the growth of swiss chard plant by both conventional chemical fertilizers and human urine as organic fertilizer in a vertical farming system. This vertical farm uses DFVH (direct feed vertical hydroponic) technology to provide necessary elements to plants for their growth like light, nutrients, water and a medium substrate to grow in, like peat and added biochar etc.

This research project was funded by the Ministry of Agriculture and Forestry of Finland by the name of BioRaki 2 (Tuni 2018) which was carried out by TAMK (Tampere University of Applied Sciences) and the facilitator company carried out the project was Evergreen Farm Oy which is located in Hiedanranta in Tampere city. Hiedanranta serves as a development hub for experiments and projects which promote sustainability, smart technologies and circular economy solutions (City of Tampere 2018).

Evergreen Farm Oy provided the vertical farming system called Grow360™ for this research to be carried out (picture 1). This system has an area of 9 m^2 and a volume of 22,5 m^3. The structure is composed of rotating 15 cylinders where up to 2160 plants can be grown vertically. each cylinder can hold up to 144 plants, which rotate continuously from 10-18 hours a day, during which 17 LED lights spread around the unit provide appropriate & customizable light wavelengths depending on the crop needs. Inside each cylinder there is a "Direct Feed" irrigation system which provide nutrients and hydration to each plant through inside filled growing substrate like peat, moss, biochar etc.

This system was specifically customized according to the parameters of the research project requirements, unlike their generically designed other systems. In this system, 8 different nutrient treatments were designed. All treatments were replicated once, except 1 treatment since the total number of cylinders were 15 which will be explained later in this paper. This study will allow us to determine two research questions. First being, what would be the yield in growth of the selected plant (swiss chard) when treated with urine concentrate versus mineral nutrient fertilizer (Yara) when using Grow360™ (vertical farm) system? And second question is that, what is the role of biochar in the growing media (peat) with different fertilizer treatments in regard to the plant growth?

PICTURE 1. Grow360™ vertical farming unit (Author 2019)

2 THEORY

2.1 Vertical farming

Urban agriculture can be described as the cultivation of plants mainly for domestic use within the urban or constructed environment. It also includes processes such as the cultivation, refining and delivery of food, similar to growing crops over large fields. The emphasis on urban farming has risen dramatically over the last few decades, due to the consequences of climate change and the need to improve food security (Wong, Teo, Shen & Yu 2020).

With growing technical inputs, the urban farming industry can be segmented into various forms: fields around urbanized areas, hoop houses, greenhouses and artificially lit indoor farming. Farming has been an outdoor activity for the majority of human history. For energy, plants collect sunlight and consume water and soil nutrients. With improving technologies, farmers have increasingly realized the advantages of indoor cultivation with greenhouses, such as year-round growing plants and improving control of pests with technologies like vertical farming. The regulated indoor agriculture environment ensures optimized development and offers a flexible way to achieve a cost-effective output. The production and management of an indoor vertical farm has four major considerations: the location, type of farm, type of crop and technology (Wong et al. 2020).

Technology deployment is also the secret to an effective vertical indoor farming. Advances in LED lighting, sensors and automation technology have allowed indoor agriculture to be more effective and suited for specific crop cultivation. In contrast to greenhouses, indoor cultivated plants depend on their growth solely on artificial lighting which can be very expensive.

2.2 Plant growth and nutrient uptake

The ability of a soil for plant growth is based on many interconnected attributes. The soil needs to be porous and permeable enough to enable the water and air to penetrate, retain and transmit freely. It should also provide a supply of nutrients to the plant roots not too rapidly leaching and it must be clean of excess salts or harmful factors and have an ideal temperature and pH range. Other than carbon dioxide from atmosphere, water extracted from the soil and radiation energy from the sun, a known number of 15 elements are essentially required for plant growth. Those nutrients are subcategorized into six macronutrients as they are needed in larger quantities and the rest of nine are micronutrients also called trace elements, as they are required in relatively smaller amounts. Macronutrients include nitrogen (N), phosphorus (P), potassium (K), sulfur (S), calcium (Ca) and magnesium (Mg) and micronutrients include manganese (Mn), iron (Fe), boron (B), zinc (Zn), copper (Cu), chlorine (Cl), molybdenum (Mo), cobalt (Co), and nickel (Ni) (Hillel 2008).

2.3 Nitrogen

Nitrogen cycle goes through processes like ammonification, nitrification, denitrification and nitrogen fixation in many forms and pass through atmosphere to soil and then to organisms and then back into the atmosphere. This helps the plants to synthesize chlorophyll from nitrogen compounds along the way and help maintain essential biological processes which are important for the existence of life (BYJU n.d.).

Although the air is 78 % nitrogen, the majority of biological structures are physiologically constrained by nitrogen because most biota cannot use molecular nitrogen as N_2. The lightning and biological fixation transforms nonreactive N_2 to reactive N via these two natural processes. The organic nitrogen as reduced N^{3-} in the form of NH_2 bonding with N is produced when the nitrogen is fixed by biological microorganisms in soils or oceans. When these organisms die, the nitrogen is released in the form of ammonium cations (NH_4^+) via mineralization (Möller 2015).

2.4 Swiss chard plant

Swiss chard, biological name *Beta Vulgaris*, is a beet spinach. It is a biennial plant which can grow up to 0,9 m in optimum conditions. It has bright red stem color with dark green leaves. It can be grown in a variety of soils ranging from sandy, loamy and clay soils. It can grow in temperatures ranging between as low as 5 °C and up to 26,6 °C, where ideal being 13 °C – 21 °C (bettervegetable-gardening n.d.). It also has a good tolerance to salinity. Their optimum pH range is 6,0 – 6,5 but it can also tolerate neutral and alkaline soils in some areas ranging from 4,2 to 8,2 (Plants for A Future n.d.).

Selection of this plant for this research project was done on the basis of its ease of cultivation, its high tolerance of weather, salinity changes resilience and high nitrogen uptake.

2.5 About human bio-waste

Human urine is a form of liquid waste from the human body which is secreted by the kidneys and extracted through the urethra from blood through urination. Since urine is produced after blood filtration into the kidneys, it contains low molecular compounds because it does not filter proteins (Karak & Bhattacharyya 2011).

Every human generates 1-1,5 liters per day in 4-5 days, while an individual excretes 500 liters of urine per year on average. Children on the other hand, urinate half of that of the amount from adults (Karak & Bhattacharyya 2011).

2.5.1 Composition

Urine is comprised of 88% nitrogen, 67% phosphorous & 73% potassium. However, amount and composition of the urine among people is diverse because of physical activity differences, environmental conditions, water, salt and high protein intakes. With urea constituents, nitrogen is released up to 10,98 g/cap/day, more than 50% of total organic solids. Other nutrients which are secreted with the urine are sulfur, magnesium, calcium and micro-nutrients like copper zinc and boron. The composition shows that urine can be processed and used in agriculture as a plant nutrient source regardless of plant requirements and soil condition (Alemayehu, Asfaw & Terife 2020).

2.5.2 UC as a fertilizer

To use urine as a fertilizer, the urine should be stored thus, becoming a urine concentrate (UC). The duration of storage depends on temperature and activity purpose. A few weeks to three months of storage results in complete hydrolysis to increase ammonia concentration and pH for further stripping. If, however, disinfection is intended then it may be stored for more than six months. UC storage eliminates any pathogens as ammonia's concentrates and pH rises, thereby, if contaminated with fecal matter. Typically, microorganisms in urine die very rapidly and are not a danger to further usage of urine as a soil fertilizer (Nagy & Zseni 2017).

Nitrogen is fixed in the fresh urine as 85% urea ($CO(NH_2)_2$) and 5% as total ammonia (NH_3 + $NH4^+$) where pH is between 4,2–6,9. Once it is stored, hydrolyzation of urine occurs and pH increases up to 9,25. If the nitrogen occurs in the form of NH_3, especially at high temperatures and if not held in tightly closed containers, ammonia volatilization and nitrogen loss can result. This may conflict with an effective recovery and even trigger odor issues, which are one explanation for the implementation challenges as well (Alemayehu et al. 2020).

2.6 Conventional fertilizer (Yara)

Yara company is a global supplier of mineral fertilizers, chemicals and environmental products. In this research, a combination of two fertilizers from this supplier were used, “Ferticare 4-17-24” and “YaraTera Calcinit” because, they are suitable for growing vegetables in greenhouse and for all growing medium. Let's call them as “Yara A” and “Yara B” respectively for ease of understanding (Yara 2018 & 2019).

Both fertilizers are in powdered form with high solubility in water and are chlorine free. The table 1 below provides the mineral concentrations offered by these two fertilizers.

TABLE 1. Mineral concentrations

Nutrient	Yara A Concentration (%)	Yara B Concentration (%)
N	4	15,5
P	7,4	-
K	19,9	-
Mg	3,3	-
S	4,4	-
Cu	0,03	-
Fe	0,24	-
Mo	0,008	-
Zn	0,03	-
B	0,05	-
Mn	0,17	-
Ca	-	19

2.7 Growing substrate significance

The horticultural industry and customers are utilizing the growing media to support plant growth. The medium ensures a stable growth for plants by supplying a range of essential elements like, physical stability, air reserve for roots, water absorption and reserving it for plant needs and nutrients supply. A number of growing substrate constituents are used like peat, wood fibers, bark, coir pith etc., as the right media balance is as essential as water and fertilizer for optimum plant development. Plant species vary significantly in need of water and nutrients and thus require multiple forms of growing media to provide the best conditions for optimum growth. The right growing medium provides stable, consistent conditions that allow the producer to achieve higher yields and increased efficiency (Growing Media Europe n.d.).

2.7.1 Peat

Peat develops when plants like peatmosses are submerged in water and just partially decomposed because of an oxygen deficiency. However, white peat is taken from the upper and younger layers of a peatland, it is thin to mildly decomposed. The plant outline is clear and yellowish brown to dark brown. White peat is the main constituent of the growing media throughout Europe and is used in all horticultural sectors. Nowadays, peat is still the main component of growing media blends and no other material incorporates as many advantageous features as this one. Its strong water retention and effective aeration are favored and with low pH and low peat nutrient content, it is possible to generate almost any kind of growing medium by incorporating liming material and fertilizers. Moreover, it is free of human and plant pathogens (Growing Media Europe n.d.).

2.7.2 Biochar

Biochar is a black solid charcoal like substance which is produced by a process called pyrolysis in which biomass or organic matter like, wood chips, pellet or husk etc., goes under thermal decomposition with a limited supply of oxygen with relatively low temperature (usually >700 °C) (International Biochar Initiative n.d.).

There are a variety of benefits of using biochar in general and in agricultural field such as: improved soil composition, increased water retention and absorption, decreased acidity, reduced nitrous oxide pollution, improved porosity, controlled nitrogen leaching, improved electrical conductivity, improved microbial properties, carbon sequestration and most of all mitigating climate change (Spears 2018). Biochar used in this project was supplied by Carbofex (Carbofex n.d.).

2.8 pH

pH is a characteristic which describes the relative alkalinity or acidity. The soil's pH has a huge effect on the biological processes of soil. The pH in soil is considered as a "master soil variable" which influences numerous biological , chemical, physical and plant growth processes and biomass yields, as shown in figure 1 (Neina 2019).

Mostly, the nutrients are available to the plants in 6,5 to 7,5 range and generally optimum for plant's root growth. At higher pH >7,5 for example, phosphates react with calcium and magnesium to form less soluble compounds. The same happens when pH decreases, generally <6,5, phosphate ions again react with aluminum and iron to form insoluble compounds thus, limiting the nutrients uptake by plants (Nutrientstewardship n.d.).

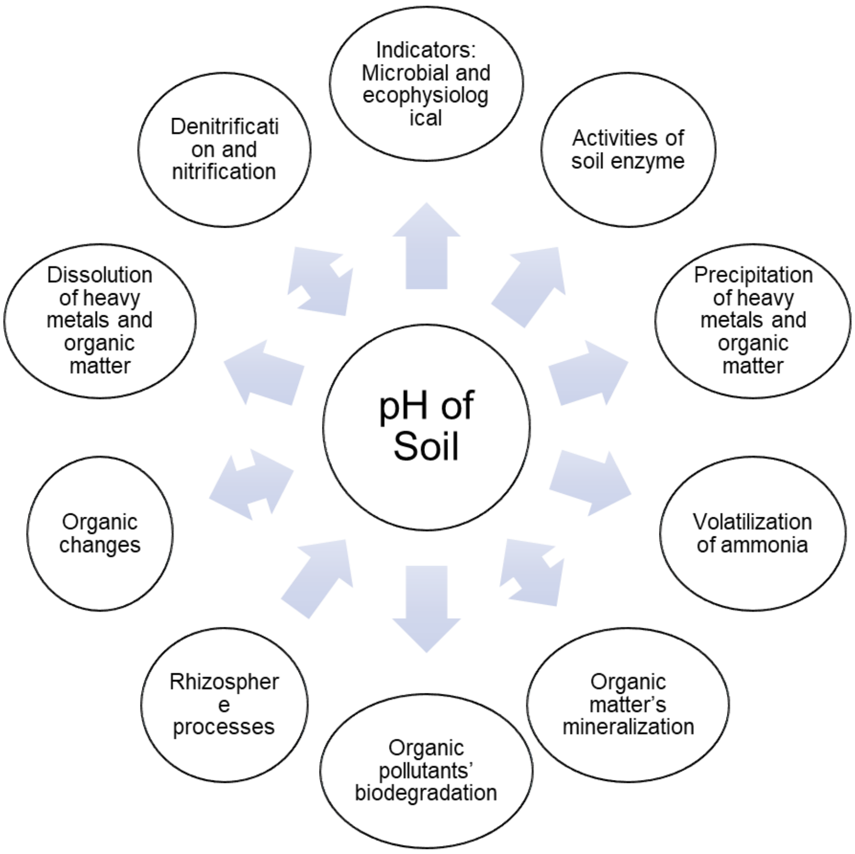


FIGURE 1. Some biogeochemical processes and their relation to soil pH (Neina 2019)

2.9 EC (electrical conductivity)

Electric conductivity (EC) is a salt concentration index and a measure of the solution's electrolyte concentration. The EC of the nutrient solution is compared to the quantity of ions available to the root zone of the plants. The optimum EC relies on crops and the climate. In general , higher EC prevents nutrient absorption by raising the nutrient solution's osmotic pressure causing waste nutrients and increasing environmental discharges of nutrients. Lower EC on the other hand may severely affect plant’s health and production (Ding, Jiang, Zhao, Guo et al. 2018).

2.10 Grow360™ unit

Grow360™ is a vertical urban farming innovation unit, developed by the company named Evergreen Farm Oy. It is an environmentally controlled structure for growing a variety of crops. The unit used in this project was a prototype and the design were customized according to the project’s parameters and fertilization requirements. The details for this unit are divided into below subtopics.

2.10.1 Structure

This unit is a 9 m^2 structure which is 6 m long, 1,5 m wide and 2,5 m high and can hold up to 15 cylinders. Each cylinder has 12 panels, and, in each panel, there are 12 plants thus, 144 plants in each cylinder making a total of 2160 plants in one unit (figure 2). Each cylinder is, approximately, 40 cm in diameter with sufficient spacing in between cylinders to allow plants to grow (Evergreen Farm Oy n.d.).

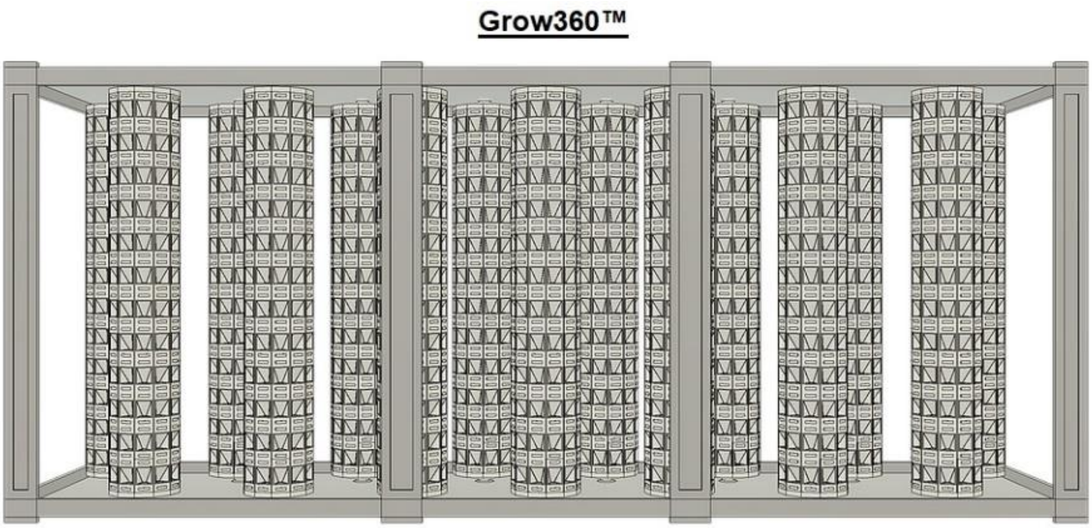


FIGURE 2. Grow360™ structure’s front view (Evergreen Farm Oy n.d.)

On the structure there are 17 LED lighting fixtures placed where proportional illumination exposure is provided to the plants. The lights provide specific wavelengths on electromagnetic spectrum for individual crops and stages and they illuminate from 10-18 hours a day depending on the crop. Within the rotating cylinders the “Direct Feed” irrigation system provides nutrients and hydration to each of the 2160 plants individually (figure 3) (Evergreen Farm Oy n.d.).

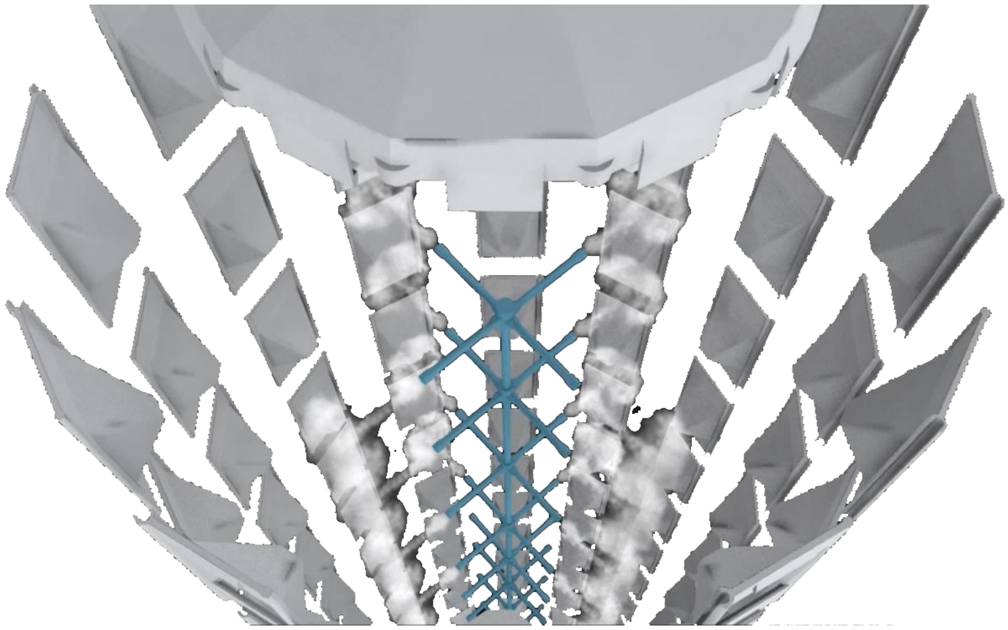


FIGURE 3. Direct feed irrigation system (Evergreen Farm Oy n.d.)

The airflow created by the rotation offers a microclimate, favorable for plants growth while keeping the leaves dry. Rotation, and thus airflow, also enables pollination without the need for manual involvement.

2.10.2 Technology

Currently the system is in prototype phase, but once it will be market ready in a couple of years from now, it will be fully automated with over 20 sensors and actuator controlled by the thoroughly integrated propriety software which would be capable of measuring and/or controlling the composition and temperature of the air, water, nutrition, light wavelengths and illuminance, leaf green area index and resources consumption, etc.

The main features of the technology can be seen in the figure 4 below.

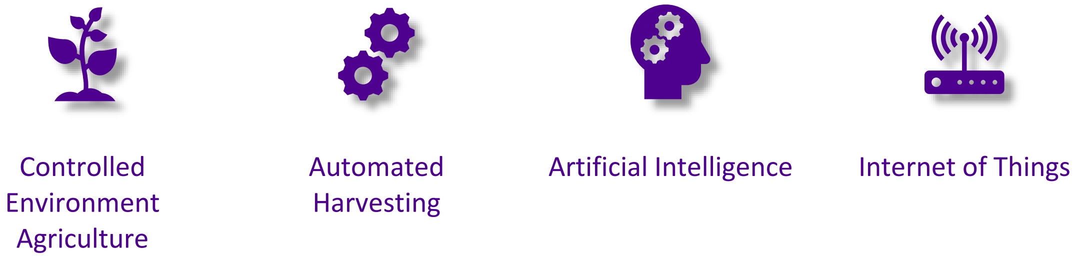


FIGURE 4. Main features of the Grow360™ technology in a nutshell

Controlled environment is further explained in the figure 5 which shows that it controls the humidity inside the unit's ambient environment and in each individual cylinder separately. It also controls the temperature, lighting, carbon dioxide, nutrient feed by automatic irrigation system and all of these parameters are controlled and automated by a central unit and their propriety software.

FIGURE 5. Controlled environment features

3 METHODS & IMPLEMENTATION

The project was divided into 5 phases.

1. Experimental setup and calculations phase.
2. Installation and testing phase.
3. Sowing phase.
4. Monitoring and data collection phase.
5. Harvesting phase.

3.1 Experimental setup and calculations

3.1.1 Setup parameters

Summary of the setup:

- Two nitrogen concentration levels, 150 mg/L and 100 mg/L were chosen for both UC and Yara fertilizers and to be delayed for 3 weeks after plant sprouts
- 8 different treatment combinations were designed.
- Each treatment was replicated once, totaling to 16 treatments. Since, there were only 15 cylinders, one treatment was excluded from replication.
- After the sowing of seeds, nutrition was to start after 3 weeks.
- 4 tanks with 1000 L capacity were installed and attached to the system for nutrition feeding.
- Temperature range 17 °C - 22 °C
- Average pH of the baskets and medium 6,0 – 6,5
- Average EC (electrical conductivity) for nutrition tanks 1,8 – 2,3 mS/cm.

These values were based on the experimental setup proposed by BioRaki2 Project and from TAMK (Viskari 2019).

3.1.2 Fertilization calculation

The concentrations of fertilizers used which were initially attained as benchmarking for further calculations, can be seen in the table 2.

TABLE 2. Concentrations of fertilizers as received.

Nutrient	UC Concentration (%)	Yara A Concentration (%)	Yara B Concentration (%)
N	0,86	0,0024	0,0093
P	0,043	0,00444	-
K	0,027	0,01194	-
Mg	0,0012	0,00198	-
S	0,57	0,00264	-
Cu	0,000006	0,000018	-
Fe	0,00025	0,000144	-
Mo	0,000055	0,0000048	-
Zn	0,000092	0,000018	-
B	0,000077	0,00003	-
Mn	0,000013	0,000102	-
Ca	-	-	0.0114

It is important to note that, the UC nutrient concentration corresponds to 500 L of stored UC gather into a tank from dry toilets in TAMK. Yara A and Yara B concentrations correspond to 600 g of each diluted to 1000 L of water since they are available in powder form only. It was critical to keep the matching nitrogen levels for both because, only then, the final results would be comparable for the two fertilizers.

Since, the amount of N is very high in UC compared to Yara fertilizers, it should correspond to the level in both Yara fertilizers combined to keep the N levels equal for different treatments. It can be derived by the equation as follows.

$$Dilution\ ratio = \frac{\%\ of\ N\ in\ UC}{\%\ of\ N\ in\ Yara\ A + Yara\ B} \tag{1}$$

Applying the values from the table 2 above and applying equation (1) we get the following result for dilution factor

$$Dilution\ ratio = \frac{0{,}86\ \%}{(0{,}0024\ \% + 0{,}0093)} = \frac{0{,}86\ \%}{0{,}0117\ \%} = 73{,}50427.$$

Using this dilution calculation basis, N amount in UC can be derived for 150 mg/L and 100 mg/L levels of concentrations in the table 3 below

TABLE 3. UC needed for fertilization.

	N in Stock (mg/L)	Needed N Level (mg/L)	Dilution Factor	Liters UC required for 1000 L Tank
UC 150	8600	150	57,33	**17,44**
UC 100	8600	100	86,00	**11,63**

Dilution factor can be obtained by dividing the concentration of N in stock by N required level. The table 4 below shows the Yara A & B quantities in mass to calculate nitrogen levels in Yara fertilizers.

TABLE 4. Yara A & B need for fertilization

	Yara 150	Yara 100
Yara A (% N)	4	4
Yara B (% N)	15.5	15.5
Yara A Mass (g)	900	900
Yara B Mass (g)	736	412
Yara A Mass of N (g)	36	36
Yara B Mass of N (g)	114.08	63.86
Total N (g)	150	100
Total N (mg/L)	**150**	**100**

In the above table 4 the mass of N in grams for each Yara A & B can be calculated by dividing percentage of N by 100 to get the value in decimal and then multiplying it with the mass of fertilizer and then adding up both masses on N to get the value of total N mass in grams and then it can be converted into amount in mg/L by multiplying and dividing by 1000.

To summarize the above calculations,17,44 L and 11,63 L of UC are required to prepare UC 150 and UC 100 nitrogen levels respectively for 2 tanks of 1000 L of each nutrition. To prepare Yara 150, 900 g and 736 g of Yara A and Yara B are needed respectively and for Yara 100, 900 g and 412 g of Yara A and Yara B are required respectively to prepare 2 more tanks of 1000 L of nutrition, each.

3.1.3 Project specific system configuration

In this project, eight different combination of treatments were used (table 5). So, the irrigation pipes coming from the tanks, and into the systems needed to be configured according to the project's parameters because, the generic design of the Grow360™ unit is constructed to be a single inlet of nutrition/water which distributes further to all 15 cylinders with same treatment.

TABLE 5. Treatment combinations

#	Peat	Biochar	Yara 150 (mg/L)	Yara 100 (mg/L)	UC 150 (mg/L)	UC 100 (mg/L)
Treatment 1	✓		✓			
Treatment 2	✓			✓		
Treatment 3	✓	✓		✓		
Treatment 4	✓	✓	✓			
Treatment 5	✓				✓	
Treatment 6	✓					✓
Treatment 7	✓	✓				✓
Treatment 8	✓	✓			✓	

The treatments with regards to the cylinders are shown in the table 6

TABLE 6. Treatments mapping and replication table

#	Cylinder	Type	Treatment Combination
1	A	Treatment 1	Peat + Yara 150
2	B	Treatment 1	Peat + Yara 150
3	C	Treatment 2	Peat + Yara 100
4	D	Treatment 2	Peat + Yara 100
5	E	Treatment 3	Peat + Biochar + Yara 100
6	F	Treatment 4	Peat + Biochar + Yara 150
7	G	Treatment 4	Peat + Biochar + Yara 150
8	H	Treatment 5	Peat + UC 150
9	I	Treatment 5	Peat + UC 150
10	J	Treatment 6	Peat + UC 100
11	K	Treatment 6	Peat + UC 100
12	L	Treatment 7	Peat + Biochar + 100
13	M	Treatment 7	Peat + Biochar + 100
14	N	Treatment 8	Peat + Biochar + 150
15	O	Treatment 8	Peat + Biochar + 150

The vertical cylinders were labeled from A to O where 7 cylinders A to G are in the front row and 8 cylinders, H to O are in the back row. The labeling and locations of the cylinders are shown in the figure 6 below as it provides the basis for further nutrition and irrigation design understanding.

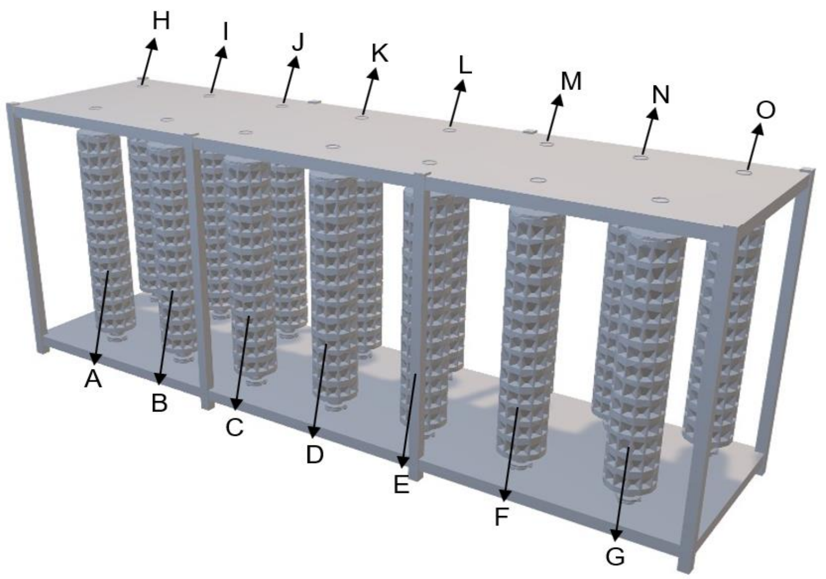


FIGURE 6. Labels and positions of cylinders in Grow360™ unit (Author 2019)

The project specific design is shown in the figure 7 below.

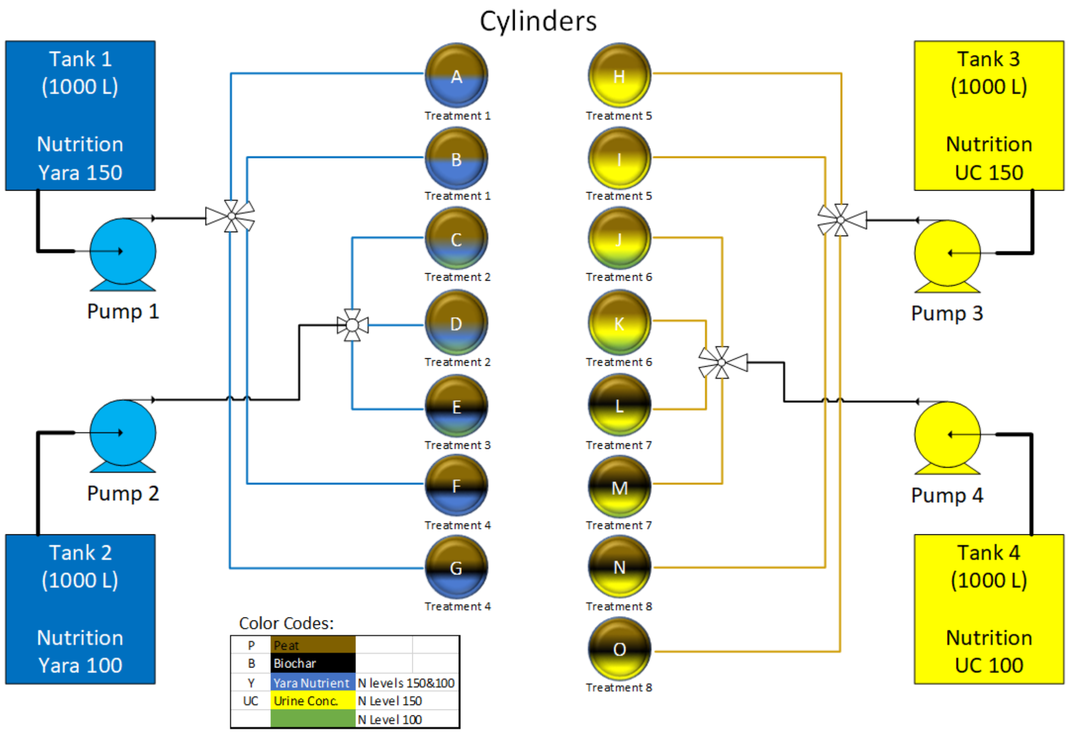


FIGURE 7. Nutrition distribution map (Author 2019)

In total there were 4 tanks which were connected to 4 pumps. Each pump was further distributing nutrition to 4 cylinders. Only the pump number 2 was distributing nutrition feed to 3 cylinders since, the total number of cylinders were 15. The blue colored tanks, pumps and piping are showing Yara fertilizers and yellow colored tanks, pumps and piping are representing the UC fertilizers. Furthermore, the peat as a medium filled inside the cylinders is shown in brown color, biochar is illustrated in black color and green color shows the lower concentration level of 100 from both Yara and UC.

3.2 Installation and testing.

The Grow360™ system was a prototype system as mentioned earlier, and it was one of its kind since, it didn’t follow the generic design. This was also the most labor-intensive part of the project.

In the very beginning of the project, there was only a skeleton structure frame existing. The Grow360™ system is a modular system, which means many small parts or modules combine to become a working unit. Primarily, a checklist was compiled for all the needed material that was needed for the unit to be finalized into a running unit as table 7.

Table 7. Material checklist

Growth & Nutrition	System Hardware	Irrigation Hardware	Monitoring Hardware
UC	Aluminum structure frame	4 centrifugal pumps with filters	18 humidity and temperature sensors
Yara A & B	15 cylinders	4 solenoids for pumps	EC meters and sensors
Swiss chard seeds	75 cargo binding belts (5 for each cylinder)	Nutrition pipes, valves and piping fixtures	pH meters and sensors
Peat	Internal irrigation pipes, nozzles and valves	4 distribution valves	CO2 sensor
Biochar	15 corrugated pipes and other PVC pipes	Control unit for automation and software	Labeler
4 nutrition tanks (1000 L each)	18 LED light fixtures and wiring	4 Flow meters with sensors	Sticky insect traps
	Plastic roll for system covering	Plywood for pumps table	
	Motor for rotating cylinders	Other hardware like bolts, nuts, tapes, plumbing tapes and connectors etc.	
	Loop belt	Tools for working	
	Belt tensioners		

Once enough material was available, the installation phase started, and initial testing took place as illustrated in the picture 2.

PICTURE 2. Pump pressure and nutrition flow testing (Author 2019)

This was done to make sure the pump has enough lifting height to provide nutrition to 4 cylinders. The test was successful to be implemented in the Grow360™ unit.

A proper platform for the 4 pumps was needed and depending on the space available, a table like shelf was built from plywood which can be seen in the picture 3.

PICTURE 3. Pumps and valve shelf installation (Author 2019)

This shelf provided a centralized control location for all the automation needed as well because it was close to the nutrition tanks and the control center mounted on the growth unit itself.

After that, LED lights were installed on the system. The base was fortified with extra aluminum rods. Water drainage tank under the system was checked for leakage. The electricity connections and wiring paths were installed for control box. Temperature and humidity sensors were installed inside the unit and also inside each cylinder. Each cylinder and basket were labeled for further monitoring.

Next, corrugated pipes were fitted in between the cylinders to ensure excessive water removal and were filled with the growing substrate on the sides. Peat was filled in all the cylinders, while biochar was filled in cylinders E, F, G, L, M, N & O as per the experimental design. The ratio of peat-biochar mixing was 70% peat and 30% biochar. All the cylinders were filled with 250 m^3 volume of the growing medium each. The medium was compacted enough so that when the nutrition would start, the medium wouldn't collapse, resulting in empty space in the upper parts of the cylinders. All the cylinders were reinforced from outside by strapping them with cargo binding belts.

A motor was installed on the ceiling with a belt connecting all the cylinders to be operated with one motor. The motor was controlled automatically by the central control system and software. Tensioners were also installed to keep the belt tight enough to prevent slipping and damaging belt-teeth. 4 nutrition tanks were also placed and near the system and hence, connected to the pumps. After that, all the piping, valves, solenoids and flow meters were installed and then connected to the actuators to be automatically controlled by the software. The whole system was covered with plastic drapes-like covers to retain the humidity and protection against dust and possible insects.

After all the installations were done, a test run was executed to check the system for any kind of possible faults or snags before sowing the seeds. The system was ready for sowing and growing phase after a satisfactory test run of the system and elimination of all the snags (picture 4).

PICTURE 4. System before sowing phase (Author 2019)

3.3 Sowing

This Grow360™ system had 15 cylinders and 144 buckets each, making a total of 2160 buckets or plants. 1 bucket from top, 1 from middle and 1 from bottom in each cylinder were intentionally kept empty to have access to the medium in order to monitor the pH and EC. Total 45 buckets were kept empty so, 2115 plants needed to be sowed and then inserted into the cylinders.

The sowing process included 2 parts. First, to fill the buckets with the growing medium and then inserting 2 seeds of swiss chard in each bucket. The purpose of sowing 2 seeds was to make sure that the germination percentage was high so that not too many buckets come out to be empty in the end when the plants sprout. In 4-5 days all the plants sprouted (picture 5) from the buckets and nutrition feed started with only water. After 3 weeks of nutrition feed with only water, the fertilizers were added into the tanks and mineral fertilization started.

PICTURE 5. Swiss chard sprouted (Author 2019)

3.4 Monitoring and data collection

A schedule was planned to monitor different parameters of the plant growth which mainly consisted of:

- Growth measurement.
- Nutrition flow.
- pH and EC measurements from medium, buckets, and tanks.
- Temperature.

3.4.1 Growth measurements

Plants growth was measured and recorded from each bucket every week. Plants length was measured from the starting point of the shoots right above the medium and till the longest leaf's end point. Measurement was taken in centimeters with an error margin of ±0,5 cm.

3.4.2 Nutrition flow

Nutrition flow was measured using the connected flow meter from each pump. A picture was taken before and after every nutrition's time slot. Nutrition was planned every other day according to the system feed dynamics, water flow and medium's moisture content. It was measures in liters for each cylinder.

3.4.3 pH and EC

pH and EC were measured 3 days a week. The measurements were taken from each cylinder's top, middle and bottom from both buckets and medium. The measurements were also taken from the nutrition tanks and recorded. pH was measured by inserting the probe from the meter directly into the medium or bucket and also by squeezing out the water.

3.4.4 Temperature

It was recorded every day from cylinders and from system's ambience.

Monitoring phase took 10 weeks in total starting from the sprouting date of the seeds till the harvesting date in which, first 3 weeks were only water and then 7 weeks were mineral nutrition with UC and Yara fertilizers.

3.5 Harvesting

After 10 weeks of growth, harvesting phase started and all the plants were harvested from the cylinders (picture 6). Each plant from each bucket was carefully pulled out with the medium not to break the roots and then the bulky substrate was gently pressed to detach it from roots an into the peat collecting waste. Then the attached substrate with the roots were washed by inserting them into a bucket of filled water and with gentle squeezing. After washing they were dried a bit and measured and weighed on measuring scales data analysis.

PICTURE 6. Harvesting and measurement of swiss chard (Author 2019)

All the harvested plants were collected into individual paper bags for each plant with corresponding labels for further analysis of nutrient content which is not covered in this research document.

4 RESULTS

The project is mainly based on the grounds to prove by experimentation whether UC has the potential to be used as an alternative to conventional fertilizers. Other factors which are prioritized after that are different nitrogen concentrations and biochar which was mixed with the peat as a substrate enhancer for plant growth. Results obtained from this research are divided into below categories.

- Growth per treatment
- UC vs Yara fertilizers
- 150 and 100 nitrogen levels nutrition
- Biochar effect on plant growth

4.1 Growth per treatment

In this category the results are compiled depending on the 8 treatments (figure 8). Since, there are now three variables; treatment, growth and number of weeks, the figure is displayed in three-dimensional bar graph to have a holistic idea of total average growth per treatment.

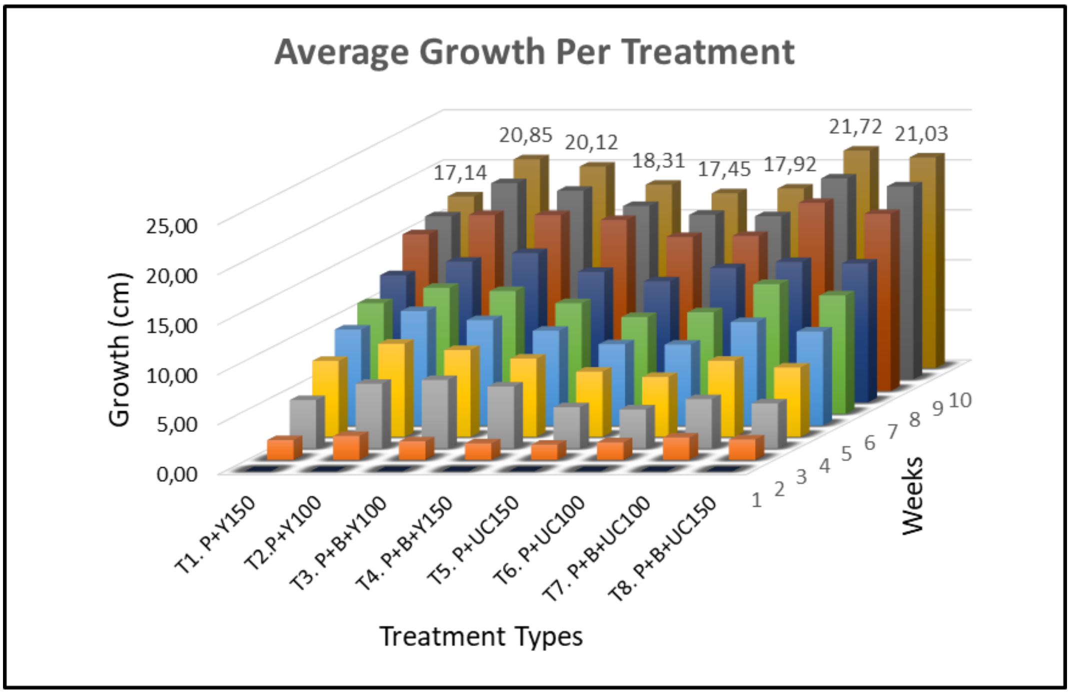


FIGURE 8. Total average growth per treatment (Author 2019)

4.2 UC vs Yara fertilizer

Plant growth data shows the fertilizers Yara and UC's comparison in the figure 9 below.

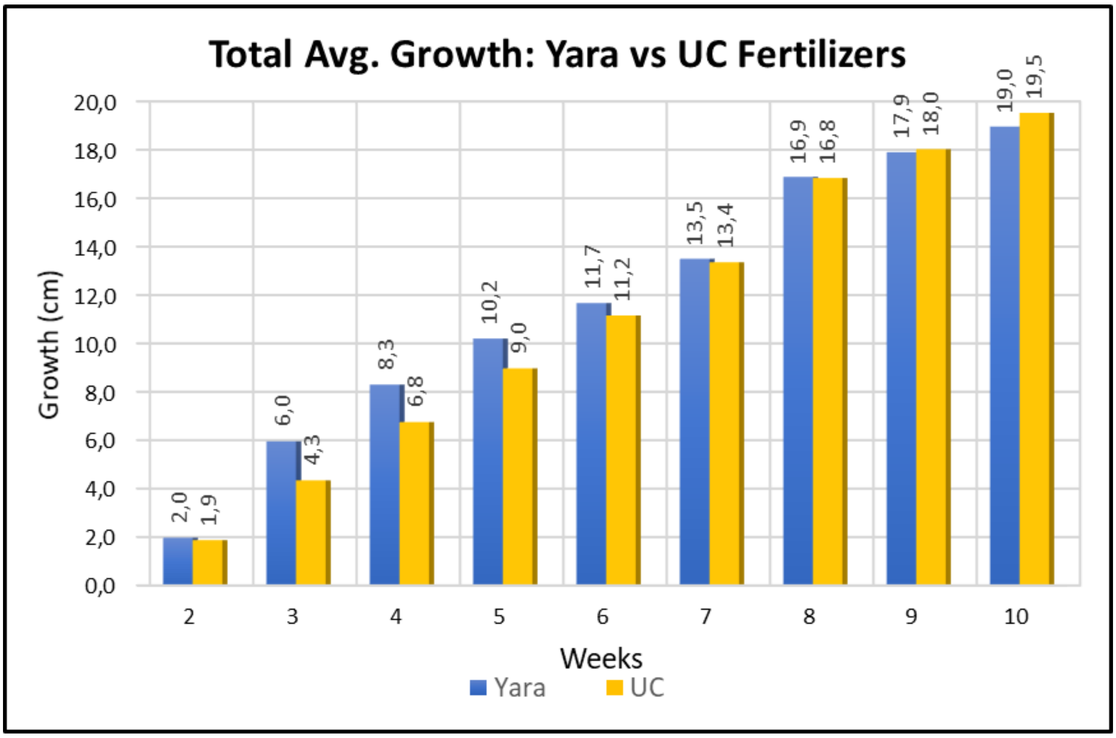


FIGURE 9. Growth comparison for two mineral fertilizers (Author 2019)

Sowing process was done in 3 days span, so not all of the plants were sprouted at the same time, it took about 4-6 days for the plants to shoot out of the growing medium so first week's growth data measurement is omitted to make sure all the plants are visible. This is why the results start from the week number two.

The figure 9 shows very interesting results. In the beginning, Plants with Yara nutrition (cylinders A to G) grew rapidly with leading gap of about 2 cm from UC nutrition (cylinders H to O). But later, plants with UC started to grow faster and at about week 8 and 9, they were about equally grown in length. In the last week plants with UC nutrition grew even longer than plants treated with Yara nutrition.

4.3 150 and 100 nitrogen concentration levels

4.3.1 UC150 vs UC100

Results for both nitrogen concentration levels are illustrated in the figure 10 below. It is best to refer to the table 6 in the section 3.1.3 to see which cylinders correspond to the mentioned treatments results.

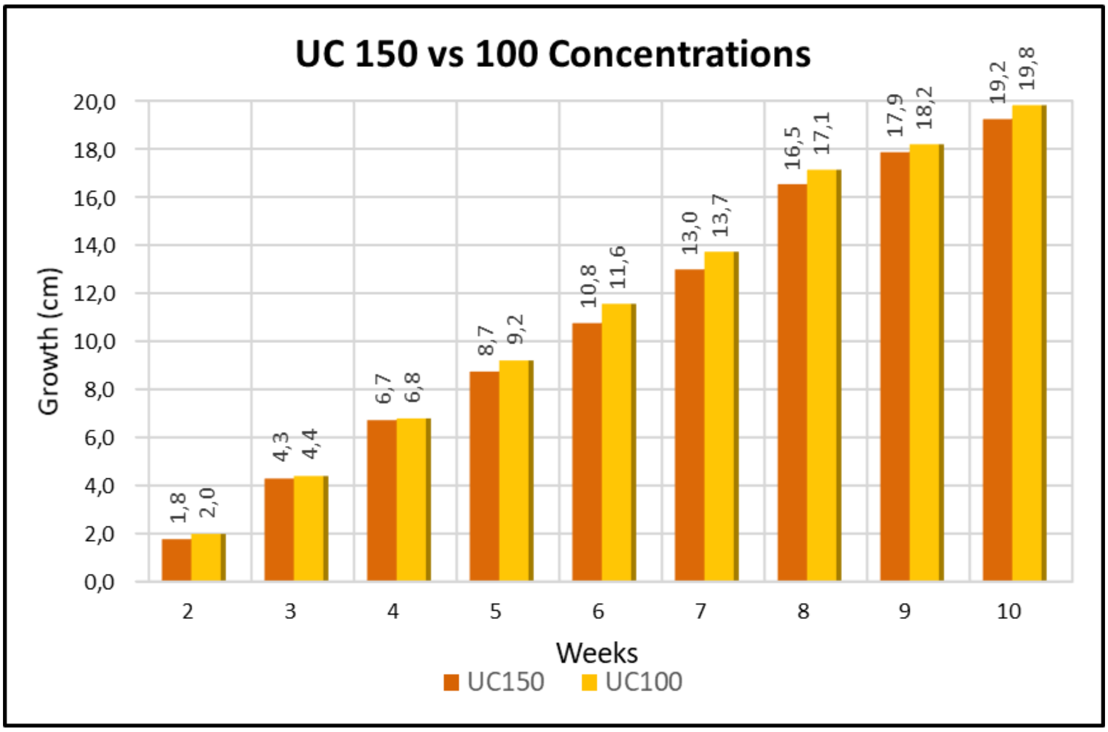


FIGURE 10. Growth with UC150 vs UC100 (Author 2019)

The results in the figure 10 above demonstrate that UC with low N level yielded better growth than 150 mg/L nitrogen concentration level. The results are the average growth values of UC150 from cylinders H, I, N & O and UC 100 contains the values from cylinders J, K, L & M which were taken every week. Biochar is in both treatments, so this comparison is valid.

4.3.2 Yara150 vs Yara100

Yara mineral fertilizer's results were obtained the same way as UC fertilizers which is shown in figure 11 below. This comparison shows a considerable growth rate in the lower nitrogen concentrations. Cylinders contained Yara150 were A, B, F & G and cylinders with Yara100 were C, D & E.

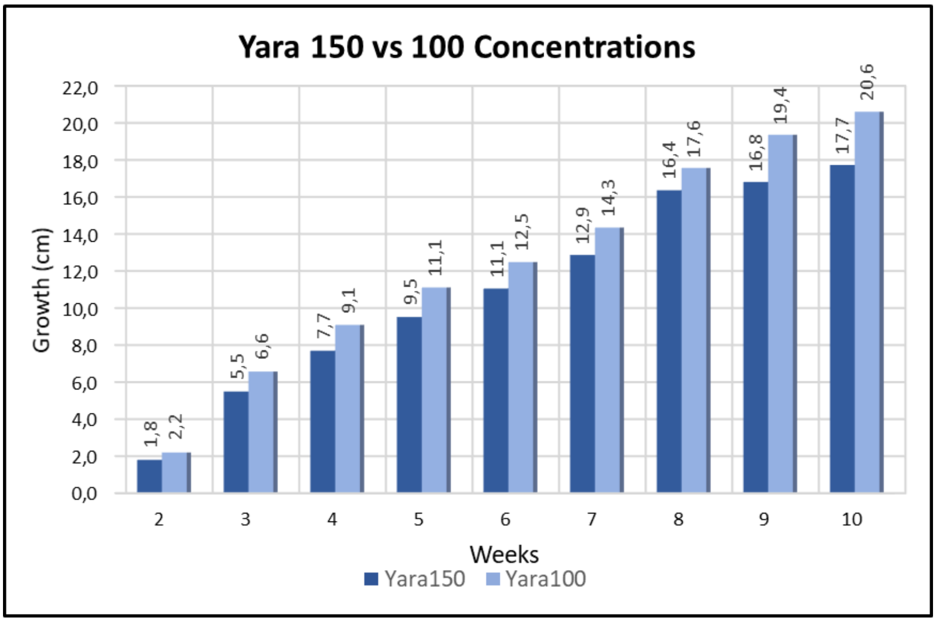


FIGURE 11. Growth with Yara150 vs Yara100 (Author 2019)

4.3.3 UC and Yara combined

Both fertilizers and levels of concentrations combined gives a visualization aid to understand plant growth which is illustrated in figure 12 below. The results show higher growth in low concentrations of nitrogen at 100 mg/L in both fertilizers.

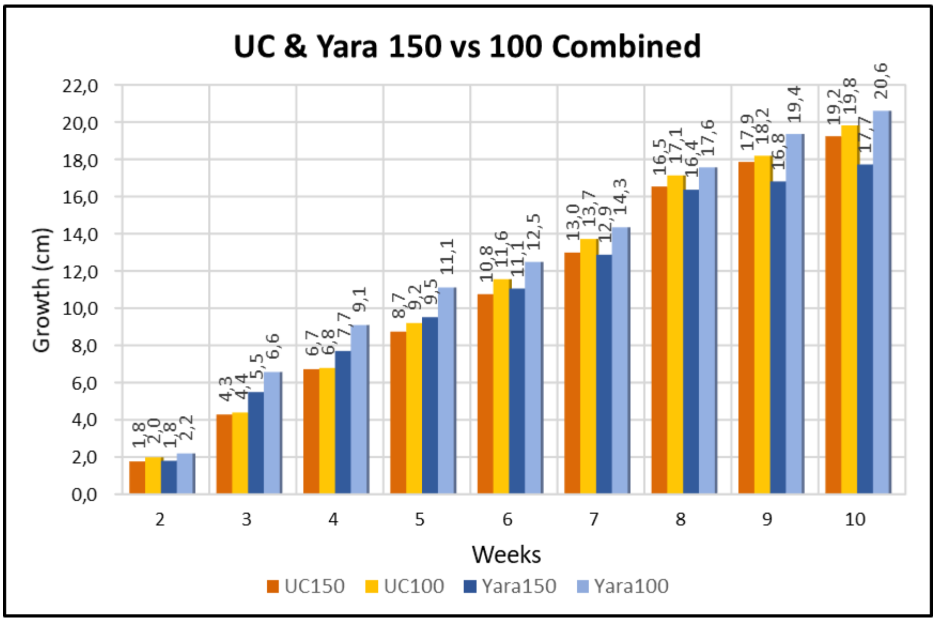


FIGURE 12. UC & Yara combined comparison (Author 2019)

4.4 Biochar effect on plant growth

Biochar addition to the peat in 7 out of 15 cylinders affected the plant growth as well. The data in the figure 13 below illustrates that plants grew longer in the growth period with the cylinders having biochar added with peat.

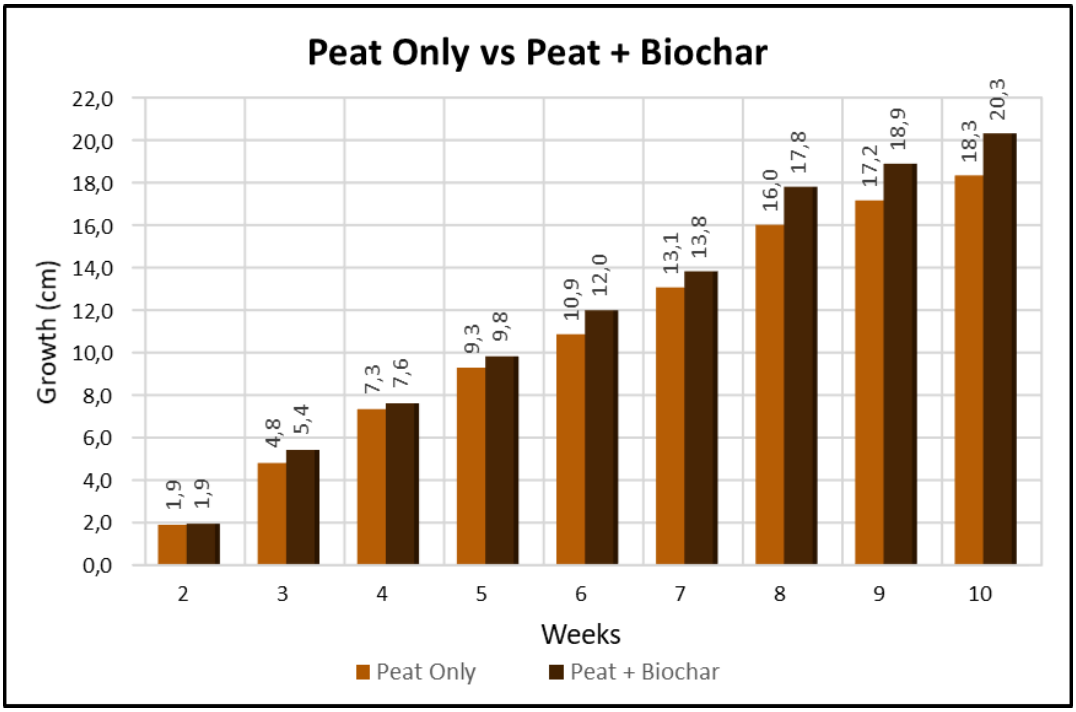


FIGURE 13. Peat only and peat with biochar added comparison (Author 2019)

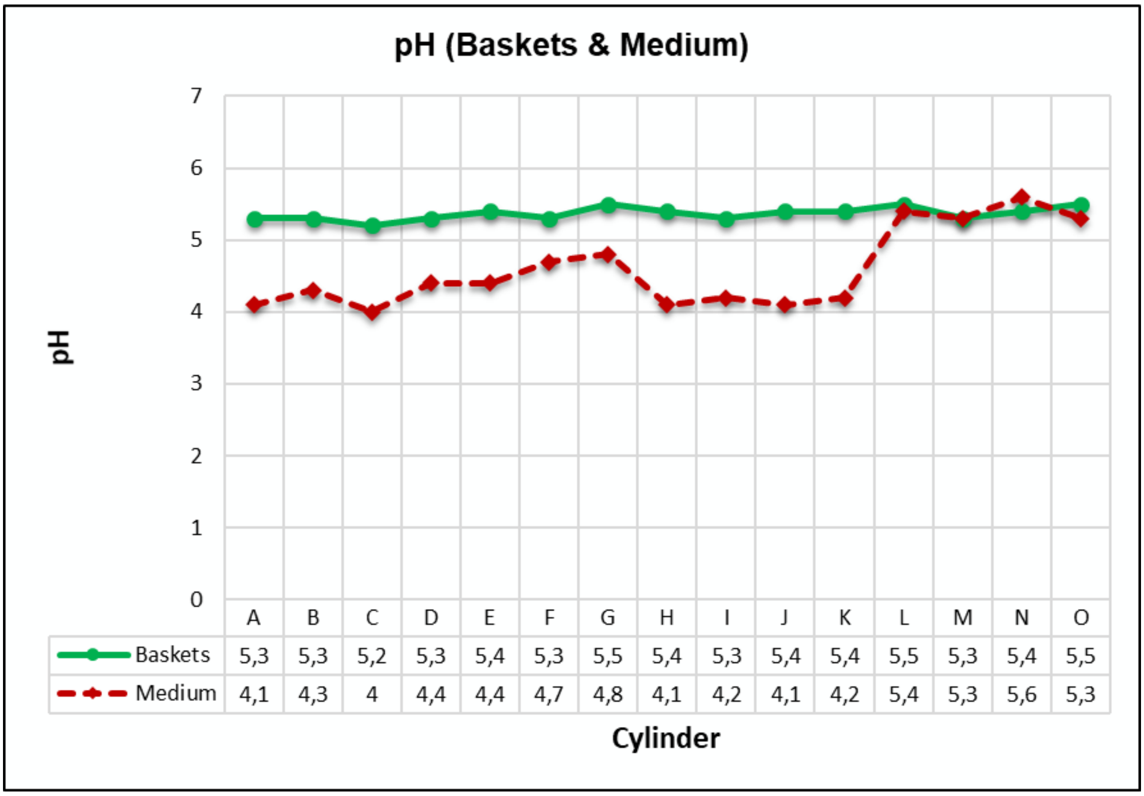
4.5 Outcome of other growth factors

Plants growth depended on other factors as well like amount of fertilizer fed, temperature, soil moisture, pH and EC. Measurements of carbon dioxide is omitted from this research because CO_2 sensor was not used in this project. In the table 8 below the water column shows water usage for initial 3 weeks and then the next column shows the amount of water with the fertilizer added was used for irrigation. Total nitrogen fed can be calculated by multiplying N concentration in mg/L with the corresponding water + fertilizer in liter and then dividing by 1000 to get the value in grams. For example, the cylinder A was fed with 9,6 g nitrogen throughout the project.

TABLE 8. Total nitrogen fed calculation table

Cylinder	Nitrogen Conc. (mg/L)	Water (before fertilizer) (L)	Water + Fertilizers (L)	Total Nitrogen Fed (g)
A	150	21	64	9,6
B	150	21	64	9,6
C	100	21	64	6,4
D	100	21	64	6,4
E	100	21	64	6,4
F	150	21	64	9,6
G	150	21	64	9,6
H	150	21	64	9,6
I	150	21	64	9,6
J	100	21	64	6,4
K	100	21	64	6,4
L	100	21	64	6,4
M	100	21	64	6,4
N	150	21	64	9,6
O	150	21	64	9,6

Results of pH are demonstrated in figure 14 below.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Baskets	5,3	5,3	5,2	5,3	5,4	5,3	5,5	5,4	5,3	5,4	5,4	5,5	5,3	5,4	5,5
Medium	4,1	4,3	4	4,4	4,4	4,7	4,8	4,1	4,2	4,1	4,2	5,4	5,3	5,6	5,3

FIGURE 14. pH of baskets and medium (Author 2019)

pH was taken from the medium inside the cylinders from 3 different levels which were top, middle and bottom and pH form the buckets were also taken from one of the buckets in top level, middle level and in the bottom level regularly as per the planned schedule. These results are average result of the pH. Electrical conductivity was also measured at the same time when the pH was being measured, and from the same probe as of pH. The device used for this purpose, shows results for both pH and EC.

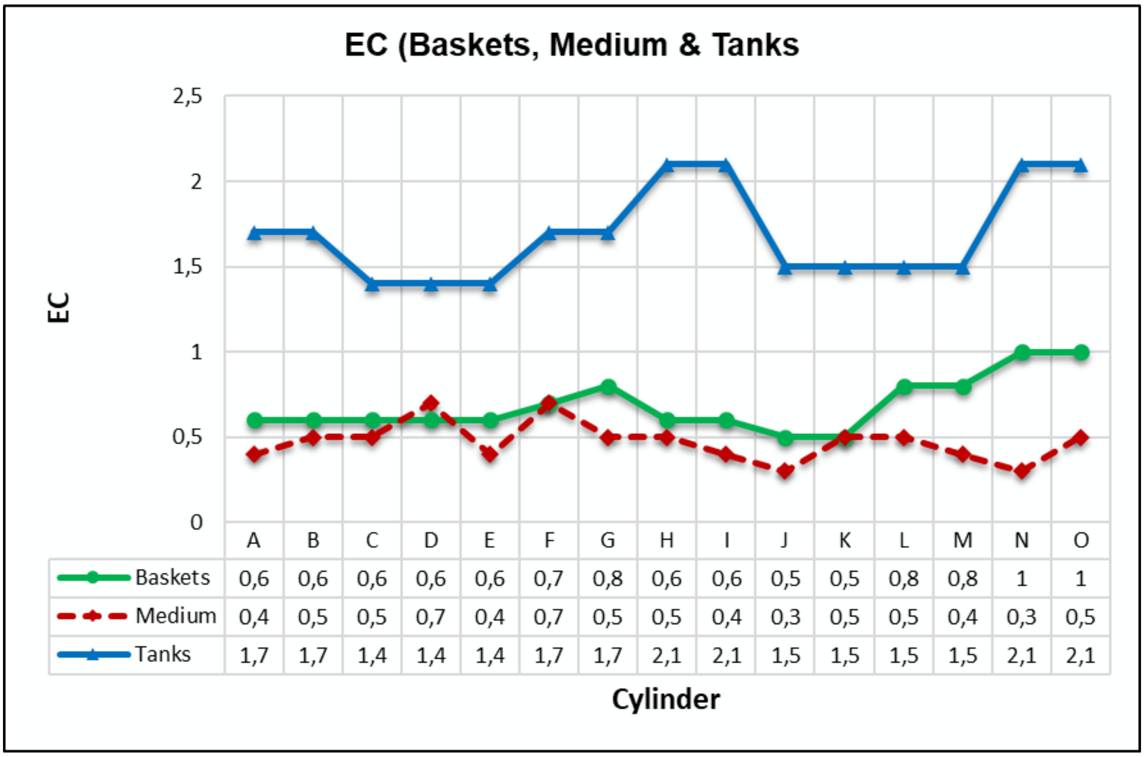


FIGURE 15. EC line graph of baskets (Author 2019)

Swiss chard's optimum range for pH and EC are 6,0 to 6,5 and 1,8 to 2,3 mS/cm respectively (Hydroponics n.d.). EC in the tanks were in the range but in the medium and buckets it was lower (figure 15). This was a good indicator because when the plants are taking up more nutrients than water, then the EC drops and if plants are taking up more water than nutrients, then the EC rises because EC is actually the measurement of the strength of a nutrient solution (Hydroponics n.d.). This showed that the plants were actively consuming nutrients.

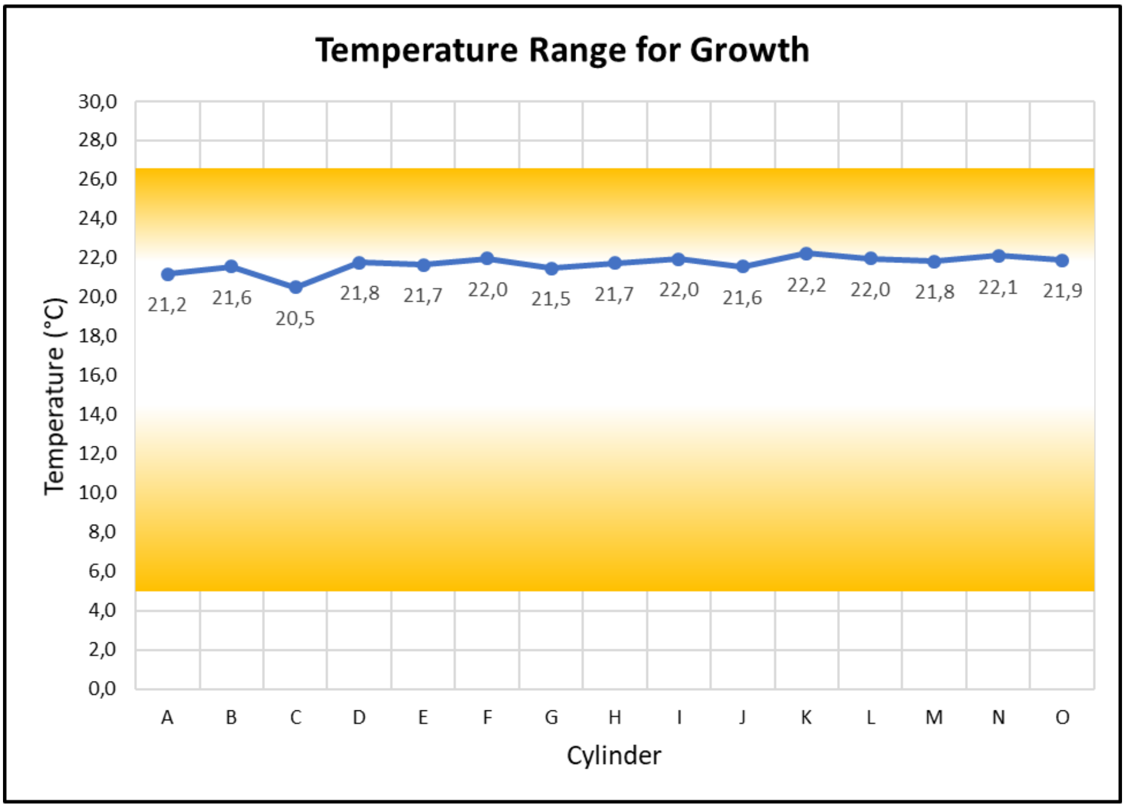


FIGURE 16. Temperature range for growth (Author 2019)

Temperature average values which were recorded for 10 weeks in the monitoring phase are illustrated in figure 16 below which show that the temperature was in the range 5 – 26,6 °C, where optimum range for swiss chard are between 13 – 21 °C.

5 DISCUSSION AND CONCLUSION

5.1 Results summary

This research project yielded some interesting results. The summary can be seen in the table 9 below.

TABLE 9. Project's results summary

Comparison Category	Result
UC vs Yara fertilizer	UC showed slow growth in the start but yielded faster growth than Yara in the last 2 weeks
UC150 vs UC100	UC100 showed better results
Yara150 vs Yara100	Yara100 showed better results
Peat only vs peat + biochar	Peat + biochar yielded better results
pH	pH in medium and buckets was lower than the optimum range (6,0 to 6,5)
Electrical conductivity	EC in nutrition tanks were in the range except for cylinders C, D, E, J, K, L & M was lower.
Temperature	Avg. temp. was in the range

In conclusion of the results, from the 8 treatments, treatment number 7 which had biochar in the medium and UC with 100 mg/L nitrogen concentration showed the highest growth with 21,72 cm average growth. On the second number the treatment 8 which had biochar mixed with the peat and UC with 150 mg/L yielded 3,18% less growth with 21,03 cm average growth. After that the treatment with only peat and Yara 100 mg/L nitrogen concentration showed the average growth of 20,85 cm. This means that the plants treated with 100 mg/L nitrogen concentration showed better growth compared to the 150 mg/L nitrogen level and biochar added peat showed better growth than only peat, which can be a good benchmark for future similar research projects.

In support to this research study, other research projects where urine was involved as a fertilizer also showed that urine-fertilized crops yielded equally good results as chemically fertilized crops. A study conducted in Kaloko Village in Zambia where urine was used as a fertilizer for growing maize and cabbage revealed that urine was as equally good as chemical fertilizer (Hannila 2008). In another research project by TAMK, lettuce was grown on a land where UC was used as a fertilizer with different nitrogen concentration levels, also resulted in admirable yield of crop compared to the conventional chemical fertilizer showing the commendable potential of human excreta to be used as an alternate source of agricultural fertilizer (Mburu 2012).

There are several other factors which may have affected results accuracy, plant growth, growing environment, nutrition feed, monitoring and Grow360™ technology etc. It is best to describe them in chronological order of occurrence in the project's timeline.

5.2 Manpower

There were 2115 plants in total which needed sowing and then later, harvesting. It would've been better that all the sowing would've been done in a single day unlike this project which took 3 days to sow seeds, so that, all the plants would germinate and sprout together to have synchronized, comparable and reliable results. The same goes for the time when the harvesting was planned. These two phases of the project needed extra manpower which should've been planned ahead and advisable for future research projects as well.

5.3 pH of peat

The peat used in this project was stored in woven polypropylene open sandbags in open roof outside the facility. This peat was already been in use by the company's other growing units, so the same peat had to be used for this project as well.

It had been raining and the pH raised from 4,5 to about 5,3 which was fortunate enough because swiss chard plant grows best in pH range of 6,0 – 6,5. But 2 weeks in, after the plants sprouted, the pH began to decrease because, rain water was replaced with fresh water while irrigation. To stabilize the pH, all the cylinders were continuously being sprayed time to time with sodium bicarbonate ($NaHCO_3$), also known as baking soda with pH of about 8,3 (PubChem n.d.) for keeping optimum pH range. The spraying couldn't reach the peat filled inside the cylinders due to the system's design. So, the only way to deliver $NaHCO_3$ was through the nutrition tanks and addition of it into the tanks was not recommended as it might affect nutrition's chemistry eventually producing uncertain results. The best resolution to this was using peat or any other medium with pre-treated lime which would've provided better results and of course this also depends on the plant's pH range for optimum growth and resilience to pH changes.

5.4 External affects around the system

The facility where the growth system was located, was a manufacturing factory as well, where these systems were built and tested like this prototype. The plants were exposed to a lot of external air passage through open doors and work dust spreading from inside even though the system was covered with plastic covers as insulation.

This situation caused "fungus gnats" to appear inside the unit. Fungus gnat is an insect which is about the size of a fruit-fly which largely affects indoor plants. Attracted to potting soil moisture, adult gnats lay their eggs (up to around 200) on organic matter near the soil surface. The adult gnats live about a week. About 3 days after laying their eggs, they hatch into larvae and burrow into the soil to feed on decaying plant material and fungi. After 2 weeks, they appear from the soil as adult gnats and repeat the cycle. They are totally harmless to humans as they don't spread diseases from bites (Burnett n.d.).

It is highly advisable that this nature of system should be in a confined space and with full insulation from external probable contaminations for better results and to avoid accidental cross contaminations in the whole system as well as the other systems near it.

Other research projects by TAMK like this where urine concentrate was used as an alternate source of fertilizer were conducted in open land, farm or indoor land/pots. This project was conducted in a vertical farm which is an urban agricultural innovation at the moment, which makes this project first of its kind. The project was a pilot project from both research organization (TAMK) and the facilitator organization (Evergreen Farm Oy).

To conclude, the aim of the project was achieved successfully. As any project, of course there were challenges faced, resource shortage arose, solution finding and improvising was done along the way and in the end, the project was completed and served the purpose of its existence.

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