Tampere University of Applied Sciences

The Influence of Biochar and Different Fertilizer Treatments on the Yield of Swiss chard in A Vertical Farming System

Ha Quang Van

BACHELOR'S THESIS
April 2020

Degree Program in Energy and Environmental Engineering

ABSTRACT

Tampereen ammattikorkeakoulu
Tampere University of Applied Sciences
Degree Program in Energy and Environmental Engineering

HA QUANG VAN:
The Influence of Biochar and Different Fertilizer Treatments on the Yield of Swiss chard in A Vertical Farming System.

Bachelor's thesis 50 pages
AUGUST 2020

In the last decades, the dependence that agriculture industry has on water and mineral fertilizers (N, P and K) has been considered as a very serious problem to human food security and climate change. For that reason, urine fertilizer was recently introduced as a combination of an old method of recycling nutrients and new advanced technology. By taking full advantage of human urine as fertilizer we can cope with many agricultural problems related to water sanitation, energy deficiency, and especially nutrient recycling.

This thesis was carried out for a project called BioRaki and the main aim was to cultivate Swiss chard (*Beta Vulgaris*) inside the Grow360 vertical farming system by utilizing mineral fertilizer and human urine fertilizer in different concentrations and in different types of growing substrates (peat and biochar). This thesis was the second part of the project where all the fresh and dried yield mass were measured, calculated and analyzed to conclude the effect of different fertilizers and the impact of substrates on the total yield of Swiss chard.

The yield by mass of Swiss chard in mineral fertilizer was higher than that when using human urine fertilizer. However, the difference was still compatible when it comes to the total mass of stem and leaf which were the vital parts of Swiss chard to be harvested and consumed. Besides, Swiss chard gives better results towards the 100 mg/L of fertilizer concentration, and it can accumulate higher nutrient demand as well as higher productivity. Furthermore, the total yield mass of peat and biochar mixture was higher than the total yield mass of peat only. Therefore, in this case, it is noticeable that peat is not a good growing medium to use as a stand-alone substrate, and it is often recommended to be mixed with other ingredients like biochar in order to achieve better moisture holding, water distribution and plant establishment.

In conclusion, the Swiss chard can obtain the highest yield for further production plan of Evergreen Farming Oy with Grow360 system and recommend human urine as a promising method to provide enough nitrogen for plants and a sustainable way to close the loop of nutrient recovery.

Key words: Swiss chard, Grow360 vertical farming system, urine fertilizer, mineral fertilizer, peat, biochar.

CONTENTS

ABBREVIATIONS AND TERMS

Al	Aluminum
B	Boron
Ca	Calcium
Cu	Copper
Fe	Iron
K	Potassium
LED	Light Emitting Diode
Mg	Magnesium
Mn	Manganese
N	Nitrogen
Na	Sodium
P	Phosphorus
S	Sulfur
SDGs	Sustainable Development Goals
TAMK	Tampere University of Applied Sciences
UN	United Nations
Zn	Zinc

1 INTRODUCTION

In the world full of chaos and fluctuation, nearly all the countries have promised to improve the planet and the life of its citizens by the end of 2030. Particularly, they have committed themselves to 17 life-changing goals, ratified by the United Nations at the UN Sustainable Development Summit in September 2015. These 17 Global Goals, also known as Sustainable Development Goals (SGDs), cover almost all life aspects from industry, agriculture, economy, environment to gender equality, education, human healthcare and well-being. Far from being indispensable and imperative, these 17 SDGs have strong effects on each other; especially the nexus of Water, Energy and Food (WEF) as the security of them becomes a central issue of sustainable development due to future uncertainties (Raude 2019).

It is indubitable that food crop production around the world is heavily rely on large amount of water consumption and mineral fertilizers (N, P and K). In fact, some regions are dealing with water sanitation and water crisis all the times. Besides, the manufacture and transportation of mineral fertilizers vastly require energy. Therefore, the dependence that agriculture has on water and mineral fertilizers should be considered as a very serious problem to human food security and climate change. Furthermore, most of the phosphate resources that is used for creating fertilizers comes from phosphate rock and due to the fact that this resource only renews over spans of millions of years in the earth's crust, it is regarded to be finite within the next 200-300 years depending on the population and food growth (Simpson 2019). However, it is said that animals and humans excrete almost 100 percent of the phosphorus they consume in food. In the past, the phosphorus in manure and waste was returned to the soil to aid in crop production as a natural cycle without the supplement of mineral fertilizers (Cho 2013). Thus, urine fertilizer was recently invented as a combination of old method of recycling nutrients and new technology of Urine - Diverting Dehydrating Toilet. By taking full advantages of human urine as fertilizer, so far, we can cope with many agricultural problems related to water sanitation, energy deficiency, and especially nutrient recycling.

This thesis is the second part of BioRaki project which is the cooperation between various universities of applied sciences in Finland with Evergreen Farming Oy and other companies in January 2020. One of the main aims of BioRaki project is to testify the efficiency of growing Swiss chard plant (*Beta Vulgaris*) inside the Grow360 system by utilizing mineral fertilizers and human urine fertilizer in different concentrations and in different types of growing substrates (peat and biochar). Besides, the project is used to compare and draw conclusion for further analysis to grow Swiss chard in Grow360 vertical farming system (Picture 1).

PICTURE 1. Grow360 system from Evergreen Farm Oy (Published with kind permission of Evergreen Farm Oy)

The first part of the project was carried out during summer 2019 with the main task of experimental setting and seedling. The growing conditions was modified and monitored throughout the whole summer in order to be ready for being harvested in the middle of September 2019. After that, all the crops were collected and measured the fresh mass as well as the fresh length before being dried at room temperature for 4 months until January 2020.

The second task of the project was to re-weigh the dried mass of the whole crops and to conduct analysis for the effects of different fertilizer treatments (type, concentration, nutrient factors) on the yields of Swiss chard. Moreover, the role of Biochar should be specified when it comes to the usage of Nitrogen fertilizer in growing crops especially in Grow360 vertical farming system.

2 THEORY

In this thesis, both urine fertilizer and mineral fertilizer are utilized in Grow360 hydroponic farming system with different concentrations and combined with different types of substrates. Thus, this Theory part will mention about the definition of nutrient recycling, especially in agricultural aspect, two main types of fertilizers (mineral fertilizer and human urine fertilizer), two substrate types (peat and biochar), as well as the significance of Swiss chard and the Evergreen's Grow 360 vertical farming system.

2.1 Agricultural nutrient recycling

Crops, in general, beside sunlight and water, require a good and balanced supply of essential mineral substances (N, P and K) in order to flourish, which leads to the implementation of mineral fertilizers to enable food security and access to enough food supply for the growing global population. However, the production of this type of fertilizer demands a lot of energy and the dependency on fossil resources needs to be rethought. In 2016, the European Innovation Partnership for Agricultural productivity and Sustainability (EIP-AGRI) held a meeting with 20 experts to discuss how to improve nutrient recycling in agriculture aspect and they proved that more attention must be paid to closing nutrient loops throughout the whole argo-food chain.

In the last decades, the dependence of agriculture on fossil based mineral resources must be considered as a very serious problem to human food security and climate change. Moreover, the estimation of the remaining amount of phosphorus in phosphate rock in nature is unsure. Based in the world's population growth rate and future requirement for nutrients, the scarcity of phosphorus must draw higher attention than ever. Therefore, the European Commission (EC) has entitled phosphate rock in the list of Critical Raw Materials (CRMs) which combine raw materials of high importance to the EU economy and of high risk associated with their supply.

As mentioned in the EIP-AGRI final meeting report, many types of resources have been recently utilized and combined with different treatment techniques in an attempt to not only mitigate environmental emissions (to avoid eutrophication) but also to recover nutrients in more plant-available form. These resources vary from downstream processing of livestock manure, agro-residues, digestate to municipal sewage sludge. Studies and researches have been done to prove the efficiency of those resources when being processed with advanced technologies nowadays. Among them, human urine has called a lot of public attention lately due to the high amount of nutrients, especially nitrogen which it retains itself.

It is estimated that the organic nitrogen content within soil is often below limit so that farmers require to exert nitrogen fertilizer as another nitrogen resource on their farm in order to obtain higher cultivation conditions as well as higher cost and economic return. It is recorded that approximately half of the food produced now in the world is supported by the use of nitrogen fertilizer and nitrogen fertilizer has made remarkable contribution to the tripling of global food production in the last 50 years (Mosier *et al.* 2004). Therefore, human urine fertilizer was introduced as a promising method to provide enough nitrogen for plant to absorb and a sustainable way to close the loop of nutrient recovery.

2.2 Types of fertilizers

2.2.1 Mineral fertilizer

According to the definition of Longman Dictionary of Environmental Science, mineral fertilizer (also known as chemical, synthetic or artificial fertilizer), is either produced industrially (as end-products or by-products of chemical production processes) or mined from natural deposits. Whereas, organic fertilizer (also known as bio-fertilizer) comes directly from farmyard manure, compost, crop residues, biosolids and human excreta. Therefore, the nutritional content of organic fertilizer is lower compared to mineral fertilizer which is concentrated and have scientifically formulated quantities. The most common sources of nutrients in mineral fertilizer are macronutrients (N, P, K), secondary nutrients (Ca, Mg, S) and

other micronutrients (B, Cu, Fe, Zn, Mn, Si, Mo, Ni) for plant use (Gupta *et al.* 2017).

Nitrogen fertilizer manufacturing is the process that extracts ammonia (NH_3) from a mixture of nitrogen in air and hydrogen in natural gas. The NH_3 is used to make nitric acid, with which is then combines to manufacture nitrate fertilizers. NH_3 is also integrated with liquid carbon dioxide (CO_2) to create urea (NH_2CONH_2) and then these products can be combined with water to generate UAN - Urea Ammonium Nitrate compound solution. Phosphorus (P) fertilizer and potassium (K) fertilizer are both come from mined ores. P is sourced from insoluble calcium phosphate rocks, whereas K is derived from old sea and lake beds formed millions of years. N, P, K fertilizers can be combined into one NPK compound fertilizer that provides 3 major nutrients for plants at the same time.

It is still a controversial topic when it comes to the advantages and disadvantages of mineral fertilizer to the environmental and human health and whether organic fertilizer is more sustainable than the chemical one. However, it is obvious that without the substantial contribution of fertilizers, the yields would fall gradually as the soil nutrient reserves are used up, and insufficient crop nutrients happens in the overall system (Isherwood 2000). On the other hand, applying excessive amount of fertilizer can also lead to drastic drawbacks on the environment and human health.

2.2.2 Urine fertilizer

Human can be their own factory to produce fertilizer because of our digestive system that can separate and concentrate our own human excreta and make them become an essential nutrient resource rather than a waste (Jaatinen 2016). As stated in *"Practical Guidance on the Use of Urine in Crop Production"* of Stockholm Environment Institute, the excreta of one person can be sufficient to fertilize 300 - 400 m^2 of field for food production per year due to incredible nutrient contents about 90% of N, 50-65% of P, 50-85% of K and other trace elements (S, Ca, Mg). If plants can utilize these organic nutrient sources and then reproduce these nutrients back to human being through vegetable diet, we can make a closed loop of nutrient recovery.

Unlike feces, which may contain less nutrient amount and higher latent health risks due to some pathogenic bacteria like Salmonella and Entamoeba coli (E. coli), urine is practically sterile when it passes out the body and poses no health risks (Grunbaum 2010). Therefore, urine is the promising future of individual and homemade fertilizer when complying strictly with the sanitation regulations. One of the most effective way to optimize all the benefit from urine and minimize risk health is the invention of Urine - Diverting Dehydrating Toilet (UDDT in short) which means that the urine is separated at time of use and is available as fertilizer while the solid wastes are being sanitized (Picture 2). Separating urine at original source brings back plenty of advantages such as reducing smell, enabling fast drying of feces and decreasing the run-off of microorganisms and nutrients to the surrounding environment (Global Dry Toilet Association of Finland - Käymäläseura Huussi ry).

PICTURE 2. Biolan Naturum UDDT installed in TAMK (Photo by: Viskari)

After being collected, the fresh urine is normally acidic (pH ≈ 6) and has to be stored undiluted in sealed containers for further uses (Dr. Viskari). As claimed in WHO guidelines, if urine is used to accelerate composting which means urine can be poured on top of compost, the storage period can take a couple of days. In case that urine is collected from a household toilet and for household purposes, it can be used after a month of storage. When it comes to public toilets and large-scale farming, the storage period needs to take up at least 6 months. During storage, pH rises up to 9-10 and Urea transforms to NH_3. Before using, urine should be diluted with ratio 1:3 (1 part of urine with 3 parts of water) in order to reduce

the risk of Nitrogen evaporation, overfertilization and damage to the plant. After sowing period, about 2 weeks old, urine can be then applied on the soil with 10 cm far from the stems and not on leaves nor on fruits to get rid of contaminants. Urine fertilizer is usually testified in normal agriculture cultivation, but some studies have recently proved that the yield in aquaculture crop behaves also incredibly well when fertilized with urine. Recycling urine as fertilizer can not only make agriculture and wastewater treatment more sustainable in developed countries, but also strengthen food production and improve sanitation system in developing countries (Grunbaum 2010). However, in some countries, there are still some thresholds where authorities and farmers doubt that urine fertilizer can carry pharmaceuticals, hormones, pathogens and heavy metals even after the storage period and whether urine fertilizer can compare with mineral fertilizers when it comes to final crop yields and economic returns. Therefore, many researchers have done studies and research with different types of plants in order to convince not only the equal efficiency between urine fertilizer and chemical fertilizer, but also the behavior and perceptional changes from our liquid waste to rich nutrient resources.

2.3 Types of substrates

2.3.1 Peat moss

Peat moss first became available to gardeners in the mid of 1970s, and since then it has revolutionized the whole agricultural aspect. Peat moss is dead dark brown fibrous material that grows slowly from sphagnum moss debris and decomposes in an oxygen-free condition beneath water surface in a peat bog or peatland. The live moss grows on top of the dead moss, and it is the dead moss that forms the peat to use in garden. After harvesting, peat moss is dried, screened and packaged in compressed bales. Approximately 3% of the Earth’s surface is covered with peat bogs that have been flourishing for thousands of years. Russia has the largest expanse in the world, followed by Canada, Finland and Sweden. Due to the fact that peat moss accumulation is around 1 mm in depth per year and takes many years for the moss turn into peat and renew the source, the widespread utilization and cultivation of peat moss is a controversial

topic throughout years. However, as being the leading world peat producer, Canada established the Canadian Sphagnum Peat Moss Association (CSPMA) to strictly comply with Canadian Government regulations and acts regarding responsible production and sustainable restoration. Therefore, only 0,03% of the natural peatland have been or are currently harvested and the growing rate is more than 70 times as fast as the harvesting phase in Canada (CSPMA).

All in all, peat moss plays an important role as a soil amendment and growing substrate due to its unique biological, chemical and physical features. First of all, peat has high acidic content (pH of 3,5 to 4,5) which helps healthy growth on acid-loving plants such as strawberries, blueberries. Besides, peat moss can absorb and retain up to 20 times its weight in water, and then releases the moisture to the plant roots as needed. It also improved the cation exchange capacity (CEC) that helps to hold onto minerals, releasing them over time and preventing the leaching of fertilizers (Carroll 2020). Peat moss is also a good source of organic matter, which will slowly degrade to feed the plants over a year or two. One of the best features of peat moss is its sterility. Unlike compost and soil, peat moss is completely sterile and harbors no disease organisms, fungus, harmful chemicals and rarely contains weeds or pests. This makes the material an optimum choice for seedling period when plants are quite vulnerable to the surrounding environment. Despite coming with lots of ideal features for growing plants, peat moss is not commonly used as a standalone product due to the fact that peat moss is an organic matter, if provided with plenty of oxygen and nitrogen, it will start to decompose and compress around plant roots. In order to become a good potting medium, it must be mixed with other ingredients to make up between one-third to two-thirds of the total amount to improve the mixture quality (Carroll 2020).

2.3.2 Biochar

In the past few years, carbon-rich biomass carbonization products, also known as biochar, have become gradually the hot topic that attracts scientific and public interest because it contains a viable option for sustainable agriculture due to its potential as a long-term sink for Carbon (C) in soil and benefit for crops (Alburquerque 2013). Inspired by investigations of Terra Preta from Amazonia, biochar is the product of thermal degradation (350°C to 1000 °C) of organic materials in

the absence of air (pyrolysis) condition with clean technology and is distinguished from charcoal by its environmentally sustainable production, quality and special usage features (Lehmann & Joseph 2015).

According to the European Biochar Certificate 2019, biochar is also defined as heterogeneous and porous substance rich in “aromatic” carbon and minerals. “Aromatic” carbon, as known as fused carbon rings are the hexagon carbon compounds which are very stable and responsible for the electrical activation of the biochar carbon sponge (Wilson 2014). Due to these unique features, between 450 BC and AD 950, the farming communities in Amazon area added biochar along with other organic and household wastes to adjust the surface soil horizon into a highly productive and fertile soil called Terra Preta (Lehmann *et al.* 2007).

As stated by Lehmann 2007 in *“Bio-energy in the dark”,* biochar has been described as a possible means to enhance soil fertility as well as other ecosystem biota and sequester carbon to mitigate climate change. The advantageous influences of biochar are determined by some of its special properties such as the high porosity which is responsible for its water retention ability, the high cation exchange capacity which impacts on the retention of nutrients and prevention from losing, and the ability of being a habitat for beneficial microorganisms which can advance the release and uptake of nutrients by plants (Atkinson *et al.* 2010). Moreover, depending on the pyrolysis temperature and resulting arrangement of the fused carbon rings, biochar can be an insulator, a semi-conductor or a conductor of electricity because these rings are special bonds that allow electrons to move around the molecule. Therefore, by acting as both a source and a sink of electrons, biochar can highly support the oxidation and reduction (redox) reactions happen in soil biochemistry (Wilson 2014).

2.4 Significance of Swiss chard

Colorful stem and bright green leaves make Swiss chard the single most glamorous garden green as well as a nutritious vegetable. Swiss chard, *Beta Vulgaris*, in the Family Chenopodiaceae, is a type of beet that does not have a bulbous and edible root (Mahr 2012). Swiss chard is a biennial plant that grows as an

annual with crinkly leaves veined in bright white, orange, magenta, red, or yellow, with firm stems to match (Schiller 2019) (Picture 3). The leaves can be eaten raw in salads or cooked as spinach, and the stems are usually chopped and served as celery. However, both consumers and farmers prefer Swiss chard due to its low price, all year round, robust and easy growing than spinach and celery. Besides, the whole plant constitutes high amount of protein, macronutrients (Ca, P, Na, K), as well as Vitamin A, B, C, K which makes this plant become a natural source of antioxidant, antidiabetic and anti-acetylcholinesterase to help the prevention of neurodegenerative and chronic diseases (Sacan & Yanardag 2010). On the other hand, Swiss chard contains significantly low amount of energy, fat and carbohydrate which is an ideal food source for weight-losing (Maynard & Hochmut, 2007).

PICTURE 3. Bunches of Swiss chard (Photo by Alex from Ithaca, NY - Swiss Chard Rainbow, CC BY 2.0, https://commons.wikimedia.org/w/index.php?curid=39688044)

Among vegetables, Swiss chard tends to accumulate more Nitrate (NO_3^-) than others and can be the one that contributes most to daily Nitrate intake. More than 60% of total Nitrate content in Swiss chard contains in the petioles, but the elimination of half of petiole during harvesting process may reduce 30% the Nitrate content and create better product within health-safe limit (Miceli *et al.* 2013).

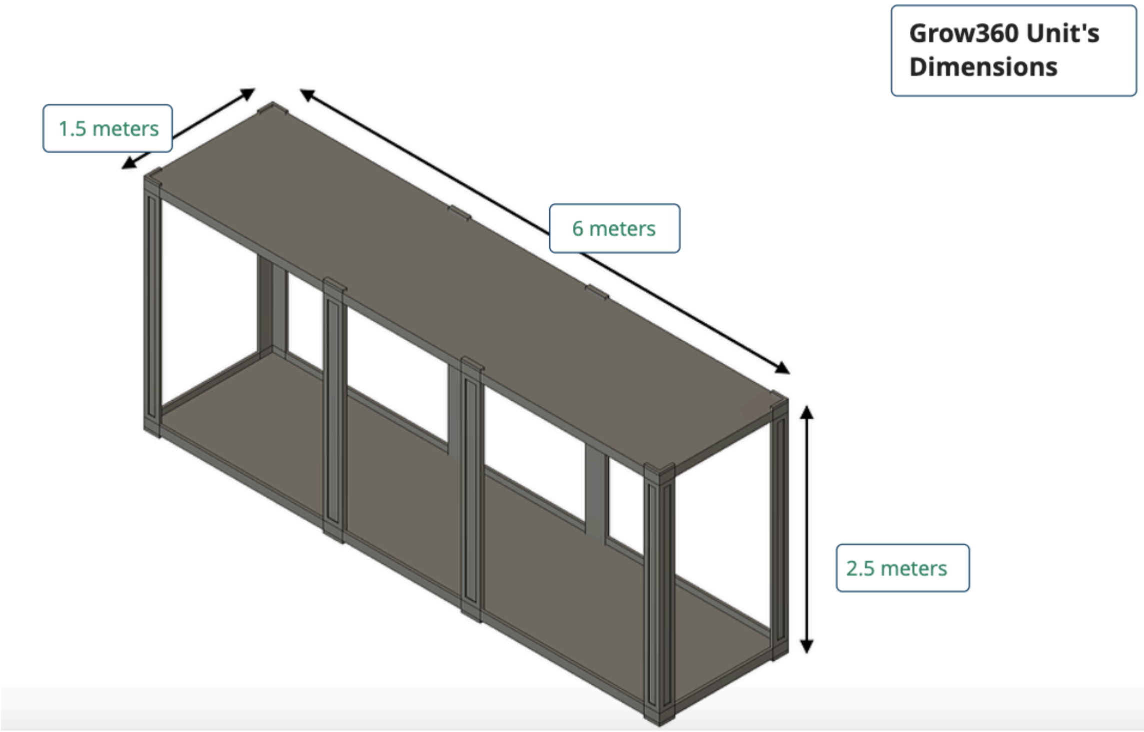
Chard plant, in general, can thrive in all temperature zones (between 5 - 35°C), but it prefers cool temperature (between 10 - 30°C) as high temperature slows down leaf production. Although chard's higher heat tolerance makes it a great salad green to grow when it gets to hot out for others, it always demands adequate watering. Beside soil temperature condition, pH is also a key element for seed germination. According to Maynard & Hochmuth in *Knot's Handbook for Vegetable Grow* 2007, Swiss chard is in the slightly tolerance group which be grown successfully on soils that are on the alkaline side of neutrality (pH 6,0 - 6,8). In addition, a high-yielding cultivation requires a location that gets full sun to part shade, and well-worked soil with good drainage and high organic content which can be supplemented by compost and/or fertilizers as needed (Schiller 2019). Moreover, Swiss chard is a very nutritive-demanding species. During the whole cultivation period, the content of mineral, total quality and yield can be strongly affected by the concentration, frequency as well as method of fertilization (Miceli *et al.* 2013). Thus, for vigorous growth, chard plant must be fed with a high nitrogen fertilizer every 4-6 weeks. The average maturity time for Swiss chard is around 50-60 days and it needs 1-1,5 inch per week of water (Schiller 2019). Based on those required growing conditions, Swiss chard is one of the best vegetables to be testified in this study in order to draw final conclusion whether the cultivation conditions within Grow360 can meet the need of growing Swiss chard.

2.5 Grow360 vertical farming system

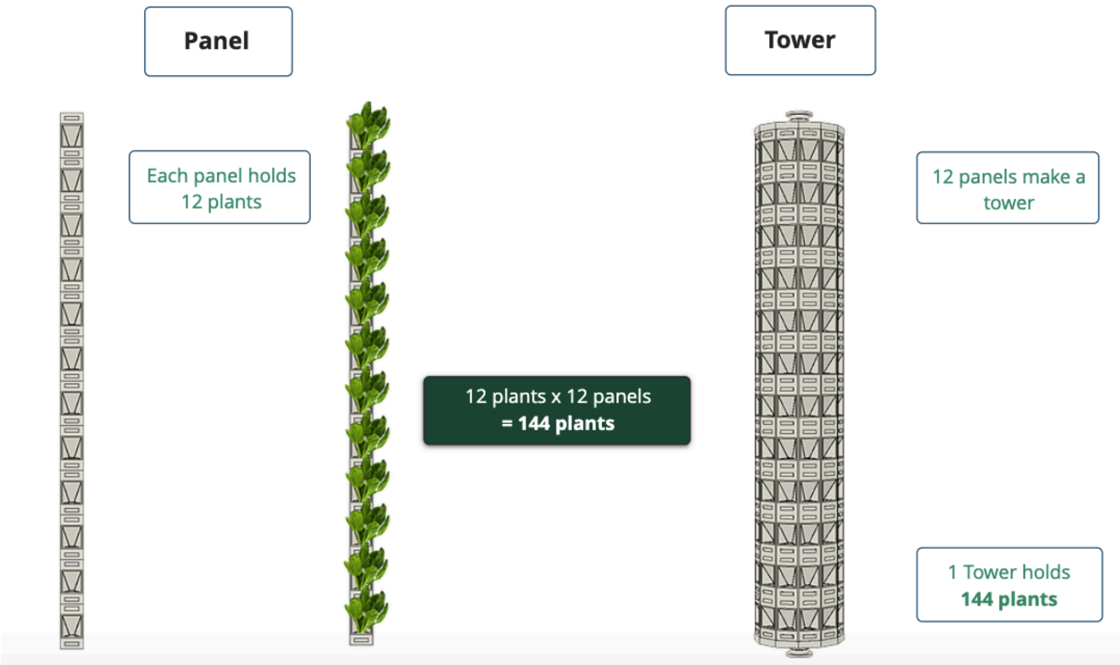
In an attempt to keep pace with the world, a Finnish-based company, located in Hiedanranta area, Tampere, Finland, Evergreen Farming Oy has established their business to achieve sustainability, the company carries out their business based on 5 core values: growing medium, nutrients, zero-waste, energy efficiency and renewable energy. Therefore, Evergreen Farming Oy has been famous for its agricultural-technological revolution of the most advanced and efficient climate-controlled vertical farming system called Grow360.

By using the basic principles of hydroponics farming, Grow360 is a buildable-indoor system that is totally independent of surrounding environmental factors such as soil, nutrients, sunlight, air, moisture, water source. Grow360 is clarified

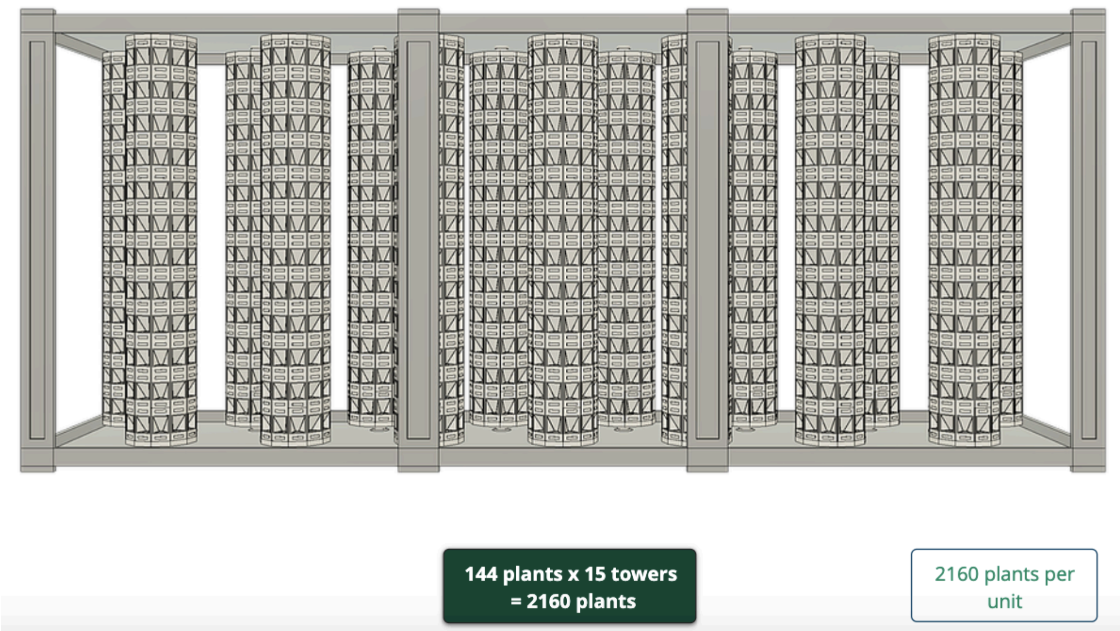
to be the highest yield per square meter and per cubic meter in the world due to its special features. The system was invented and constructed by Ali Amirlatify - the President and Managing Director of Evergreen Farm Oy. The first pilot plant of Grow360 unit was located in Hiedanranta, North West of Tampere City, Finland since 2015. Grow360 is a compact indoor system sized $9m^2$ with 3 dimensions described in Picture 4. Inside the nine-square-meter platform, there are 15 upright cylinder towers in total. Each tower consists of 12 vertical panels and 12 plants per panel (Picture 5). Thus, in general, there are 144 plants can be cultivated inside each tower and 2160 plants for the whole system (Picture 6).



PICTURE 4. Grow360 unit sized $9m^2$ (Published with kind permission of Evergreen Farm Oy)



PICTURE 5. The structure of Grow360 cylinder tower (Published with kind permission of Evergreen Farm Oy)



PICTURE 6. The demonstration of inside Grow360 system (Published with kind permission of Evergreen Farm Oy)

As shown in Picture 6, the towers are in zigzag place within 2 rows so that it gives maximum ability to grow and minimize the total cultivation area of the system. The tower rotates gradually around its axis in order to increase the possibility for the plants to evenly get in touch with light and prevent from being burnt directly.

There are 16 LED lights placed inside the system which illuminate optimum wavelengths for specific plants and grow stages. As specified by Evergreen Farm Oy, water mixed with nutrients is the key element for hydroponics farming and will be pumped, recycled and rotated regularly inside the towers. Other factors such as humidity, temperature, pH, air quality can be controlled automatically by software and actuators not only to ensure adequate living conditions but also intensify the productivity. Moreover, the whole system is powered by 100% renewable and clean energy from a solar and wind compact power system. In general, this brilliant Grow360 vertical system from Evergreen Farm Oy can not only solve many environmental issues but also create a living masterpiece of art for horticulture and deserve the Global Forum for Innovations in Agriculture (GFIA) for the Best Farming Indoor System Innovation in February 2018.

3 METHOD

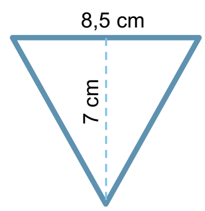
The BioRaki project was divided into two main parts and conducted by two students of Tampere University of Applied Sciences with the support of staffs and supervisors. The first part of the project was located inside an old factory in Hiedanranta area, Tampere, Finland that was convenient in terms of logistics and monitoring. The main work in this first part were experimental setting, and there were 8 growing media were chosen with different types of nutrients, different concentration as well as different substrates. Then seedling and monitoring process will be briefly mentioned below. This part was carried out during the whole summer 2019 and ready to be harvested in the middle of September 2019. The second part of the project continued by collecting and measuring all the crops' fresh mass and fresh lengths before being transported to Tampere University premises and dried at room temperature for 4 months until January 2020.

3.1 Growing system setup

The system of this project was Grow360 vertical farming system, provided by Evergreen Farm Oy. As described above, Grow360 is a compact indoor system sized 9m^2 with 3 dimensions (1,5m × 6m × 2,5m). Inside the nine-square-meter platform, there are 15 upright cylinder towers in total. Each tower consists of 12 vertical panels and 12 plants per panel. Thus, in general, there are 144 plants can be cultivated inside each tower and 2160 plants for the whole system.

Calculation of growing area:

- Growing area of 1 triangular slot:



$$S = \frac{1}{2} \times 7cm \times 8{,}5\ cm = 29{,}75\ cm^2 = 2{,}975 \times 10^{-3}\ m^2$$

- Growing area of 1-cylinder tower (144 slots):

$$S = 2{,}975 \times 10^{-3}\ m^2 \times 144 = 0{,}4284\ m^2$$

- Growing area of the whole system (15 towers):
  $S = 0{,}4284\,m^2 \times 15 = 6{,}426\,m^2$

- The whole system needs 333 L water consumption per week.
  $$\Longrightarrow \frac{333\ {}^{L\,water}\!/_{week}}{15\,towers} = 22{,}2\ \frac{{}^{L\,water}\!/_{week}}{tower}$$

The chosen plant for this experiment was Swiss chard (*Beta Vulgaris)*, in the Family Chenopodiaceae, is a type of beet that does not have a bulbous and edible root (Mahr 2012). The target of this experiment was to testify the functionality in cultivation between nitrogen mineral fertilizer and human urine fertilizer. Therefore, among vegetables, Swiss chard demands high organic content and tends to accumulate more nitrate (NO_3^-) than others and can be the one that contributes most to daily nitrate intake for human beings. Besides, Swiss chard is prone to salinity, neutral pH, wide range of temperature, average irrigation, and moisture.

Calculation of Nitrogen needed to grow Swiss chard:

- Growing time: 8 weeks
- Adding fertilizer time: 6 weeks (after 2 weeks of sowing and thinning)
- Nitrogen level for fertilizer of Swiss chard:
  $$= 170\frac{kg\,N}{ha} = \frac{170\,kg\,N}{10\,000\,m^2} = 17\ \frac{g\,N}{m^2}$$

- Nitrogen level for fertilizer of Swiss chard needed in 1 tower:
  $$= 17\ \frac{g\,N}{m^2} \times 0{,}4284\,m^2 = 7{,}28\frac{g\,N}{tower}$$

- Nitrogen level for fertilizer of Swiss chard needed in 1 tower in 1 week:
  $$= 7{,}28\frac{g\,N}{tower} \div 6\,weeks = 1{,}21\ \frac{{}^{g\,N}\!/_{week}}{tower}$$

- Nitrogen will be provided to the plants by different types of fertilizers in the liquid form which means that fertilizer will be mixed and diluted with water and supplied through irrigation system. Therefore, the nitrogen level mixed with water in 1 tower in 1 week:

$$= \frac{1,21\ g\ N}{22,2\ L\ water} \times 10^3 \frac{mg\ N}{g\ N} = 54,68\ \frac{mg\ N}{L\ water}$$

3.2 Growing treatments

3.2.1 Mineral fertilizers

In order to testify the functionality in cultivation of different types of liquid fertilizer product on Swiss chard yield, two types of mineral fertilizers and one type of human urine fertilizer were used in this project. Two types of mineral fertilizers were Yara FERTICARE 4-17-24 and YaraTera CALCINIT. Both were come from International Yara Fertilizer Company, but they contained different amount of nutrients for different using purposes.

PICTURE 10. Yara FERTICARE 4-17-24 product.

PICTURE 11. YaraTera CALCINIT Product.

Yara FERTICARE 4-17-24 comes in powdery form and consists of various nutrient elements such as macronutrients (N, P, K) and many other secondary nutrients (Mg, S, B, Cu, Fe, Zn, Mn, Mo) for plant use (Table 1). However, the percentage of Total Nitrogen (nitrate in this case) was rather low due to its specially

designed for greenhouse crop cultivation. Thus, it is blended with another type of YaraTera CALCILNIT fertilizer.

YaraTera CALCINIT fertilizer is also a product from International Yara Company. It is a fully water-soluble fertilizer come in powdery form. This fertilizer is specially intended for nitrogen and calcium fertilization. Therefore, although it has few nutrient elements, it contains significantly high amount of calcium and total nitrogen (nitrate and ammonium in this case) (Table 1). It is also recommended to be suitable for irrigation fertilization as well as foliar fertilization. These two mineral fertilizers were blended and then diluted with water into two concentration 100 mg/L and 150 mg/L for different treatments.

TABLE 1. Three types of fertilizers were used in this project.

	Yara FERTICARE	YaraTera CALCINIT	Concentrated Urine Fertilizer
Nutrients	%		
N	4	15,5	23,2
P	7,4	-	1,2
K	19,9	-	7,3
$SO4^{2-}$	-	-	45,9
S	4,4	-	-
Cl^{-}	-	-	13
Fe	0,24	-	0,0068
Cu	0,03	-	0,0002
Zn	0,03	-	0,0002
Ca	-	19	0,0002
Mn	0,17	-	0,0004
Na	-	-	8,9
Mg	3,3	-	0,0324
B	0,05	-	0,0021
E. coli	-	-	0
Salmonella	-	-	0

3.2.2 Urine fertilizer

On the other hand, human urine fertilizer was taken form one source in a public toilet in Kulttuuritila Kuivaamo which is a venue built into an old drying plant that can be rented for various cultural events in Hiedanranta area, Tampere, Finland. The urine was collected, stored in closed tanks and concentrated in order to retain higher dose of nutrients before being transported to the nearby Grow360 cultivation area. After being concentrated, the dry matter content was calculated about 37 g/kg (3,7%) and measured the nutrient content within the concentrated urine. As can be seen in Table 1, this type of urine comprises valuable nutrient elements and some salts. Specially, it contains no pathogens (E. coli and Salmonella) according to Annex IV of the Decree of the Finnish Ministry of Agriculture and Forestry on Fertilizer Products. Therefore, it is acceptable for cultivation purposes. The concentrated urine was then diluted with water into two concentration 100 mg/L and 150 mg/L to transmitted inside towers of Grow360 system. Table 1 illustrates the comparison between those three fertilizers were used in the system. It is obvious that when concentrated urine was used as fertilizer, the nutrient content, especially nitrogen amount is comparable to that in mineral fertilizers.

3.2.3 Substrates

Substrates play an important role not only in horticulture but also in Grow360 vertical farming system because they act like substances that increase the water or nutrient retention capacity. Moreover, they can be an ideal habitat for microorganisms to nourish and many reactions to happen. A good substrate can directly influence the growth, development and maintenance of the root system and the final crop yields (Olaria 2016). Furthermore, when it comes to organic farming, it is particularly important to choose a suitable substrate because the limitation in the application of non-chemical fertilizers makes substrates the only source available to the plant. There are two types of substrates were utilized in this experiment: peat and biochar. It is noticeable that peat is the most widely studied and used around the world. However, peat is now considered to be a non-renewable resource and its use in the organic agriculture must be gradually decreased.

PICTURE 12. CARBOFEX biochar product (Published with kind permission of Carbofex Oy)

On the other hand, biochar becomes increasingly approved and analyzed as peat substitute in the future. In order to evaluate main physical and chemical characteristics of this biomaterial as well as its effects on plant growth and nutrient uptake, biochar product form CARBOFEX Company (Picture 12) was testified in this experiment but in the mixture with peat.

TABLE 2. CARBOFEX Biochar features

Content	Description
Surface area	550 m/g
Fixed Carbon	> 90%
Bulk density	~ 200 kg/m^3
Conductivity	21,5 mS/m
Moisture content	30 - 50%
Ash	1,6 - 4%
pH	10
Total N	0,6 - 0,8%
Total P	270 mg/kg
Water-soluble P	< 10 mg/kg
Total K	3200 mg/kg

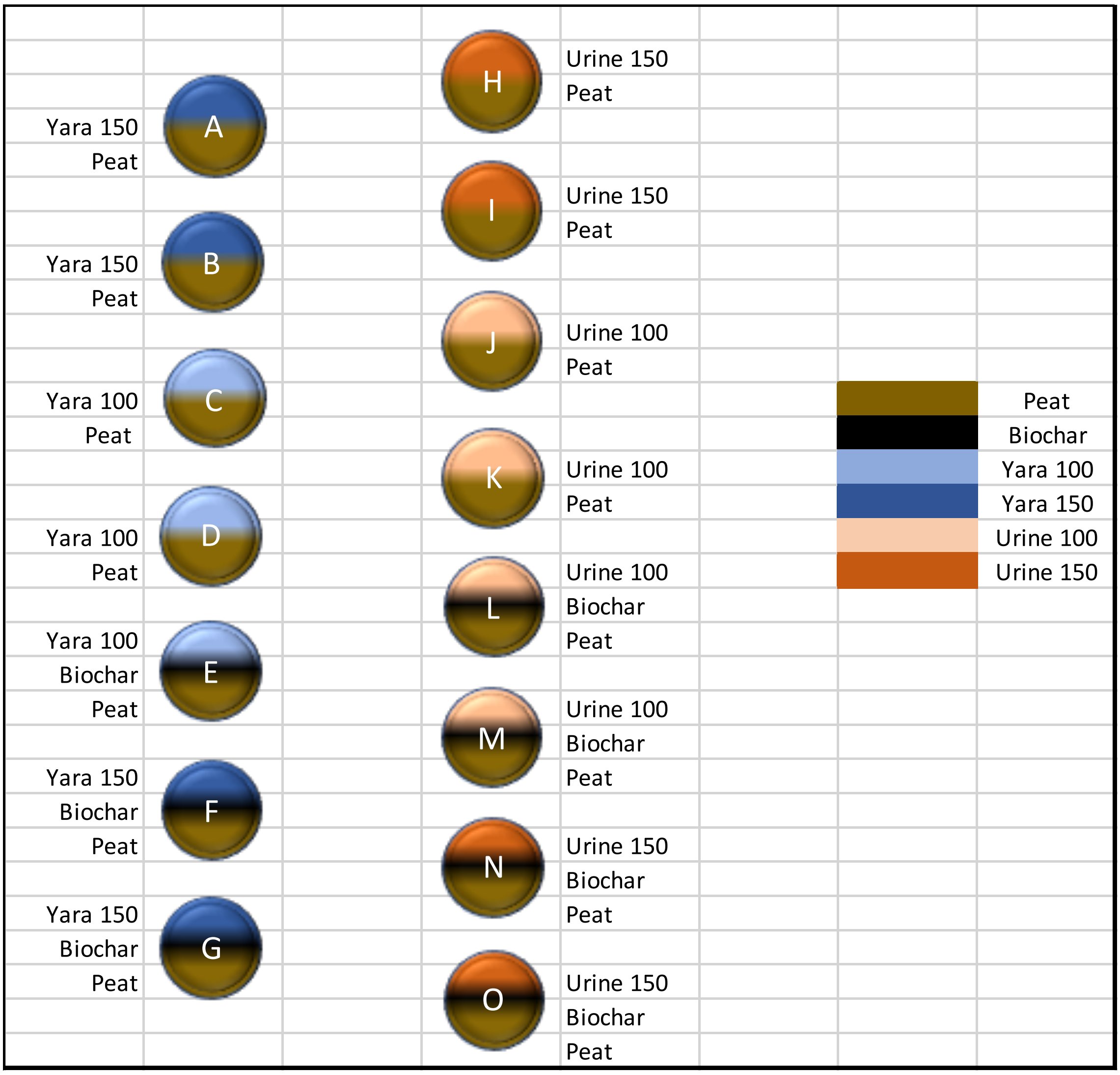
Water-soluble K	1990 mg/kg
Zn	56 mg/kg
Ni	13 mg/kg
Cr	13 mg/kg
Cu	4,7 mg/kg
Pb	4,2 mg/kg
As	< 0,5 mg/kg
Cd	0,04 mg/kg
Hg	< 0,02 mg/kg

CARBOFEX is a Finnish-based company, located also in Hiedanranta area, Tampere, and is specialized in biochar products and technology. Their biochar product is approved for organic food production and produced of Program for the Endorsement of Forest Certification (PEFC) certified feedstock which is from renewable biomass. They are also the only biochar producer has got the European Biochar Certificate (EBC) in Northern Europe which indicates that their feedstock and production chain is sustainable, and the product is in high quality. As presented in Table 2, Carbofex biochar product contains a wide range of macronutrients, secondary nutrients and some heavy metal traces but no toxic or chemicals. Besides, it also has high water, air and nutrient retention ability, high drainage ability which allows gas transmits to and from roots, and pH around 10 that easily to modify. Moreover, Carbofex biochar product is specified to have high cation exchange capacity and provide shelter for soil microbial communities and mycorrhizal fungi which have disease restraining and plant growth enhancing qualities.

Peat was mixed with biochar in ratio 7:3, respectively of the total amounts of substrate in each cylinder. The benefits of blending substrates are better moisture holding, water distribution and plant establishment. Two types of substrates were carefully prepared and moisturized with water before adding to the core of each cylinder (Picture 13 and 14).

PICTURE 13. Well-prepared peat as substrate.

PICTURE 14. Well-prepared peat and biochar (ratio 7:3) as substrate.



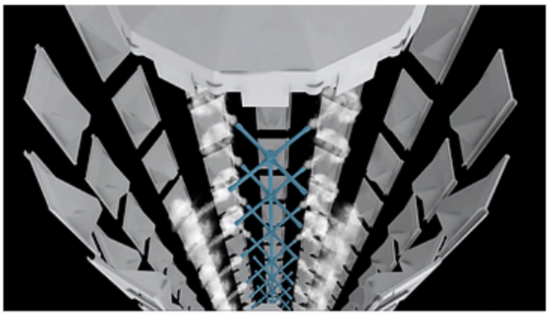
PICTURE 15. Distribution of fertilizers and substrates in 15 towers.

Picture 15 above illustrates an overview description on how the experimental setup for this project inside Grow360 vertical farming system with 15 towers in total. The core of its tower is occupied with different concentrations of different fertilizers and with different types of substrates. Each tower has one duplicate growing medium except for Tower E. This setup will provide a wide range of results to be further analyzed and compared.

3.3 Seedling, growing and maintenance

After the system setup, and chosen the right amount of fertilizers as well as substrates, the project was continued with seedling, growing and maintenance phase starting in the middle of July 2019. This part was conducted by different students and staffs from TAMK; thus, it will be mentioned thoroughly in another thesis.
As mentioned above, Swiss chard was first selected to be the growing plant in this project due to its maturity time, high nutritive demand (nitrogen), ability to withstand salinity, neutral pH, wide range of temperature, average irrigation, and moisture.

First of all, Swiss chard seeds were planted at the depth of 1,3 cm inside each triangular slot of 15 towers. The soil was then moistened and shined by 16 LED lights placed inside the system which illuminate optimum wavelengths for specific grow stages. Inside 15 towers were filled up with substrates (peat or peat and biochar with volume ratio of 7:3) according to Picture 15. The special feature of utilizing Grow360 system is that fertilizer was diluted and mixed with water to form liquid nutrient. And every 2 to 3 days, it can be pumped through Direct Feed mist irrigation system and travel through substrates layer inside the towers and then spread the nutrients towards a thin soil layer in 144 triangular spots (Picture 16). Water is then can be treated and recycle into the system to create a closed loop of water and nutrient circulation (Picture 17).



PICTURE 16. Direct Feed mist Irrigation system inside towers

PICTURE 17. Water and nutrient circulation.

(Published with kind permission of Evergreen Farm Oy)

After two weeks of sowing, when the seeds had sprouted, they were thinned to one or two seedlings per triangular slot in order to get rid of excessive competition for space, water, nutrients and air circulation. The whole system was automatically maintained and monitored through a software where it controlled over 20 sensors and actuators for air (CO_2, O_2, O_3), water (nutrition level, pH, flowrate, temperature, consumption), light (wavelengths, illuminance, consumption), cylinder towers (inside temperature, inside humidity, rotation), and for plants (green area index, growth rate, diseases, yield mass, quality). The software can keep track of every single change inside the Grow360 vertical farming system and inform as soon as possible in order to be modified and sustained for an optimum growing period.

3.4 Harvesting and measuring

After 8 weeks of growing, in the middle of September 2019, Swiss chard was mature and ready to be harvested for further analysis. Unfortunately, the harvesting period was taken longer than expected due to careful picking and lack of personnel. Therefore, during the harvesting stage, the system was cut down lightning and temperature in an attempt to slow down the growing stage of Swiss chard and have enough time to gather in all the crop at the same phase (Picture 18).

PICTURE 18. The Grow360 system during harvesting stage (Photo: Honkala 2019).

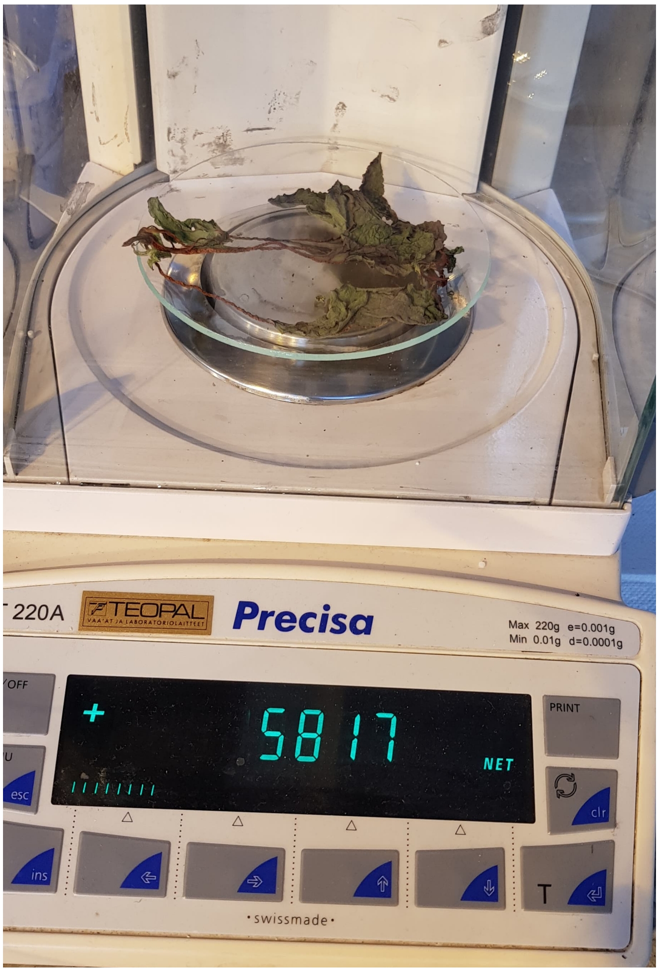
All the plants were meticulously collected the leaves, the stems and also the roots and then placed inside papers bags which had been marked correspond with tower's name and plant's number (Picture 19 and 20). After that, every bag was measured the total fresh mass and total fresh length and noted down before the root was cut down and separated. It was then measured the root mass as well as the root length so as to calculate the mass and length parameters of the stem and leaves without root. It took 8 days in total to harvest and finish all the measurements due to the huge amount of crop yields.

PICTURE 19 and 20. The plants was placed on the bags marked with tower's name and plant's number (Photo: Honkala 2019).

3.5 Drying and measuring

All the crops were then transported and air-dried in room temperature for more than 3 months starting from September 2019 until January 2020 inside TAMK premises. This long period of time was suitable for plants to totally get rid of the water content and be ready for further analysis. Swiss chard was then weighed again for dried mass with and without the root (Picture 21, 22 and 23). All the yield data was noted down and stored for further analysis and comparison.

PICTURE 21 and 22. Air-dried Swiss chard with separated root.



PICTURE 23. Air-dried Swiss chard was weighed again for dried mass.

4 RESULTS

4.1 Overview

TABLE 3. An overview of all measured results.

NUTRIENT AND SUBSTRATE	AVERAGE FRESH MASS			AVERAGE DRIED MASS		
	Total Mass	*Leaf Mass*	*Root Mass*	*Total Mass*	*Leaf Mass*	*Root Mass*
Yara 100 and Peat	7,332	6,387	0,185	1,138	1,061	0,035
Yara 100 and Peat + Biochar	6,680	5,522	0,103	0,913	0,841	0,032
Yara 150 and Peat	3,919	3,801	0,088	0,617	0,575	0,019
Yara 150 and Peat + Biochar	3,462	3,339	0,125	0,739	0,687	0,023
Urine 100 and Peat + Biochar	6,607	6,388	0,154	0,934	0,879	0,024
Urine 150 and Peat + Biochar	4,958	4,815	0,122	0,674	0,635	0,018
Urine 100 and Peat	3,680	3,555	0,185	0,568	0,533	0,026
Urine 150 and Peat	2,862	2,735	0,245	0,437	0,401	0,033

Table 3 represents a summary of all mass measured data. The results consisted of 8 different treatment types and around 1152 plants in total. The average fresh mass and dried mass results were collected and analyzed deeper based on 3 categories: Nutrient types (Yara fertilizer or concentrated urine fertilizer), nutrient concentrations (100mg/L or 150 mg/L), and types of substrates (peat or peat and biochar). Besides, the fresh root length was recorded and also water content in leaf was calculated based on fresh and dried leaf mass.

4.1.1 Average fresh mass

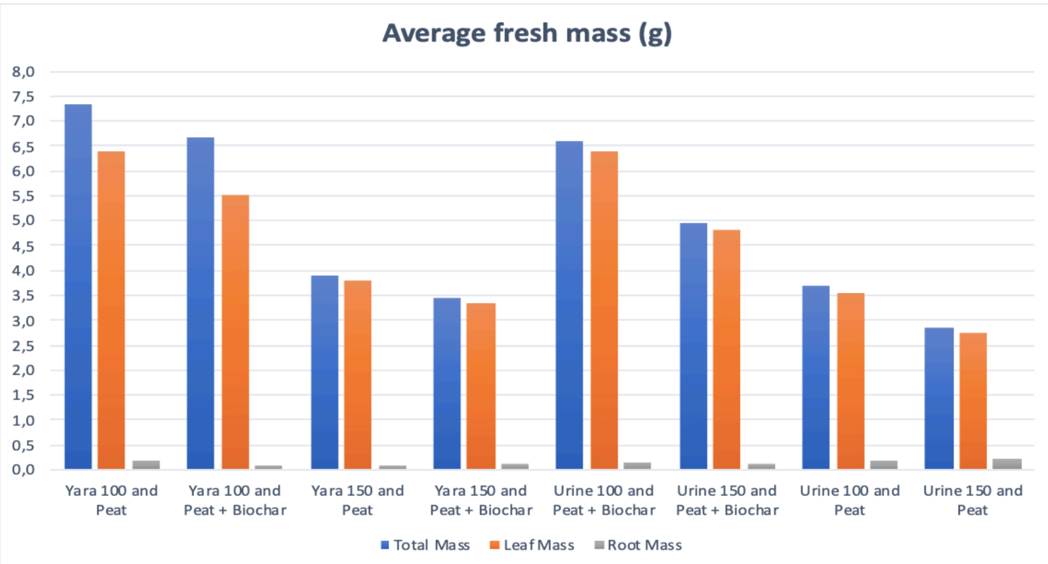


FIGURE 1. Average fresh mass graph.

As can be seen in Table 3 and Figure 1 below, Yara 100 mg/L combined with peat produced the highest Swiss chard yield (7,332g average) in this experiment, followed by the method of using Yara 100 mg/L combined with peat and biochar. Surprisingly, concentrated urine fertilizer 100 mg/L collaborated with peat and biochar as substrates also brought nearly the same productivity, more than 90% compared to the highest.

On the other hand, the combination of concentrated urine 150 mg/L and peat only produced 2,862g Swiss chard on average which was the lowest crop yield in this experiment and accounted for only 40% of the highest one. Moreover, Swiss chard showed an ability to produce an approximately similar yield when it was planted with treatment Yara 150 mg/L and peat, or treatment Yara 150 mg/L and peat + biochar or treatment concentrated urine 100 mg/L and peat.

When it comes to average fresh leaf mass, the collaboration between Yara 100 mg/L and peat presented exactly the same amount (6,387g) the total weight of leaves and stems compared to the usage of Concentrated Urine 100 mg/L and peat + biochar. It was interesting that when using the same substrates (peat +biochar) and the same nutrient concentration (100 mg/L), Yara brought out higher Swiss chard total mass but lower leaf yield than those in Concentrated Urine fertilizer.

4.1.2 Average dried mass

Figure 2 demonstrated the average dried Swiss chard mass after more than three months of air-drying at room temperature. The highest and the second highest dried mass also belonged to 100 mg/L Yara nutrient combined with peat and 100 mg/L concentrated urine fertilizer combined with peat and biochar, 1,138g and 0,934g respectively. The third place was for the combination of Yara 100 mg/L and peat + biochar with 0,913g.

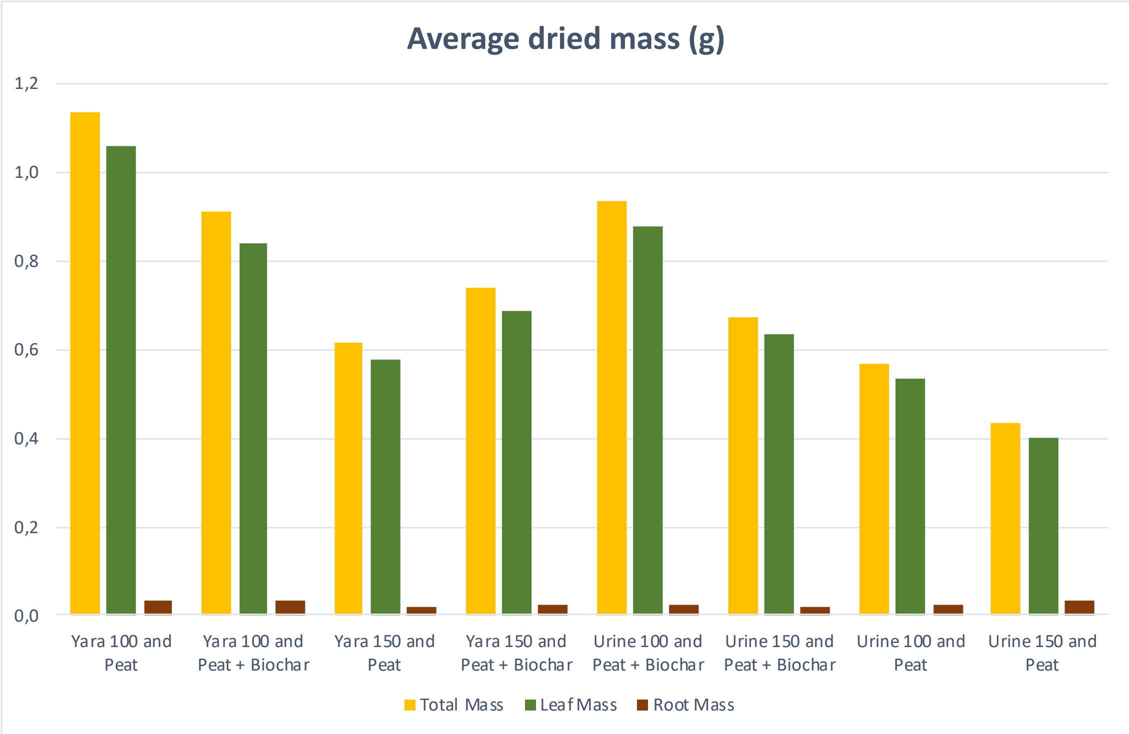


FIGURE 2. Average dried mass graph.

The most significant part was that within 150 mg/L Yara fertilizer, while having a higher total fresh mass, peat as substrate showed a lower total dried mass when compared with a mixture peat and biochar. This special feature meant that the Swiss chard crop which was planted in 150 mg/L Yara nutrient and peat as substrate had a relatively high-water content. This factor will be specified in Figure 5 below. The other three treatments illustrated the same characteristics as in fresh weight.

4.2 The effects of nutrient concentration and types on the yield of Swiss chard

Figure 3 demonstrated a closer look on how Swiss chard yield behave due to different types of nutrients. The chart was represented a specific trend for Yara fertilizer on the left side and concentrated urine fertilizer on the right side. Overall, by using Yara fertilizer, the total yield of Swiss chard (21,392g) was higher than that when using concentrated urine fertilizer (18,106g). Besides, although the total yield of Swiss chard planted in concentrated urine nutrient only equaled 85%

of that in Yara nutrient, the total leaf mass in concentrated urine nutrient constituted up to 92% of that in Yara which brought up compatible results. All in all, although Swiss chard showed better results when using Yara fertilizers in this case, the total crop yield from concentrated urine was still competitive.

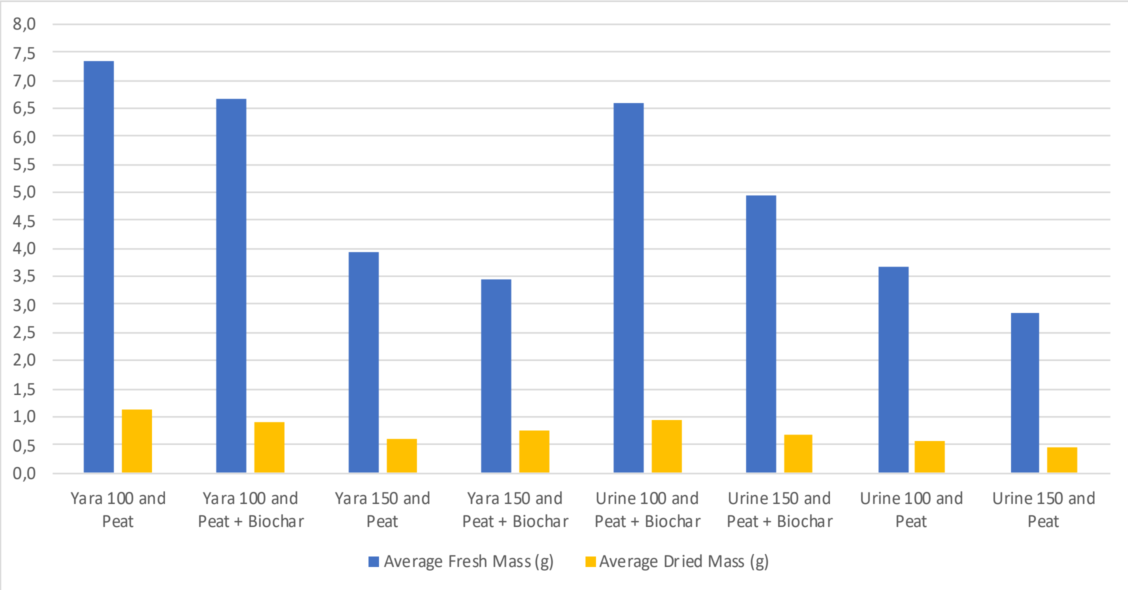


FIGURE 3. Average fresh mass and dried mass of 8 treatments demonstrate based on nutrient types.

When it comes to nutrient concentration, as being demonstrated in Figure 3, it is obvious that the combined yield mass produced from 100 mg/L of fertilizers showed a better result (more than 60% of the total harvest yield) in this case. To be more specific, within Yara fertilizer, the total yield when applying concentration 150 mg/L (7,381 g) only accounted for 50% of the total yield gained from 100 mg/L (14,012 g). Furthermore, when utilizing concentrated urine, the total yield mass from 100 mg/L was 10,287 g whereas the crop mass harvested from 150 mg/L was only 7,52 g in total. Thus, Swiss chard strives towards the 100 mg/L of fertilizer that it can accumulate higher nutrient demand and gain higher productivity.

4.3 The effects of substrate types on the yield of Swiss chard

Beside analyzing the productivity of Swiss chard between Yara fertilizer and concentrated urine fertilizer, the other main objective of this project was to testify the

efficiency between peat as a stand-alone substrate and mixture of peat and biochar (ratio 7:3). As being shown in Figure 4, although the combination of peat and Yara in 100 mg/L gained the highest result after all, the total Swiss chard yield that peat brought was 17,793 g while those result of peat and biochar mixture was about 4 g higher. Therefore, in this case, it is noticeable that peat is not a good growing medium to use as a stand-alone substrate, and it is usually recommended to be mixed with other ingredients like biochar in order to achieve better moisture holding, water distribution and plant establishment.

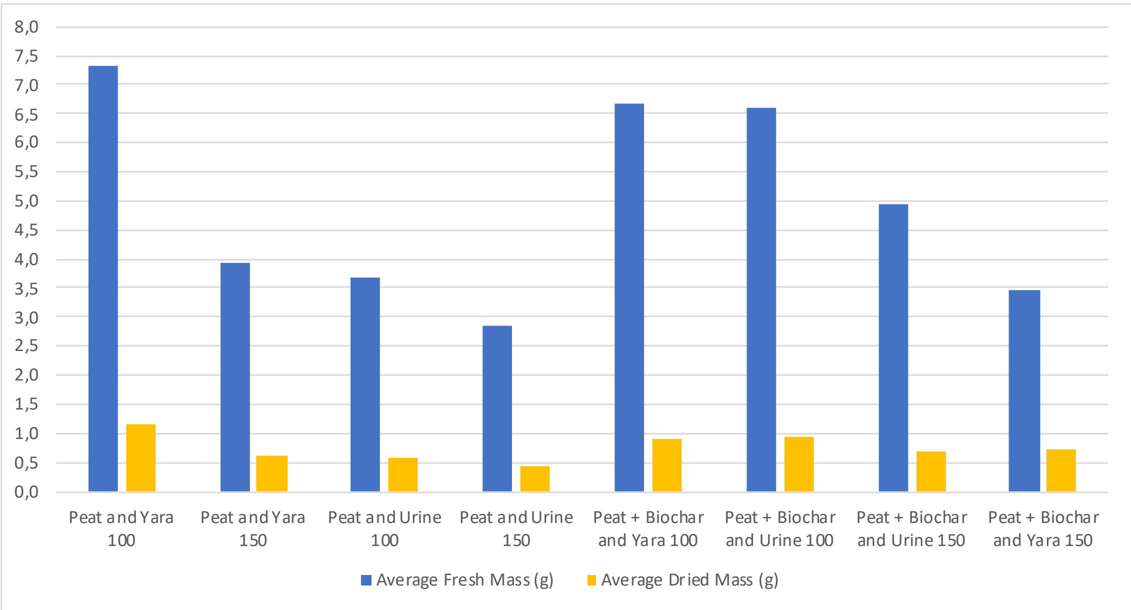


FIGURE 4. Average fresh mass and dried mass of 8 treatments demonstrate based on substrate types.

4.4 Water content in leaf

In this case, the leaf mass represented the total mass of leaves and stems; thus, the water content in Swiss chard will be calculated based primarily on this leaf mass. It is well-known that 80-95% of a plant is water because is a delivery mechanism for any nutrients that are not tightly bound to the soil. Therefore, it is essential to examine the water content within Swiss chard leaves and stems in order to know whether these nutrients are delivered from the soil to the plant roots. As can be seen from Figure 5 below, the water content within Swiss chard was ranging from 83% to 87%; despite the fact that the cooperation treatment of Yara

fertilizer in 150 mg/L and peat + biochar spotted a lower water content. As a result, it brought back a relatively low total yield mass. On the whole, as being irrigated through Direct Feed mist irrigation system inside Grow360, Swiss chard still have a great ability to absorb and transfer water from roots to other parts to nourish the plant.

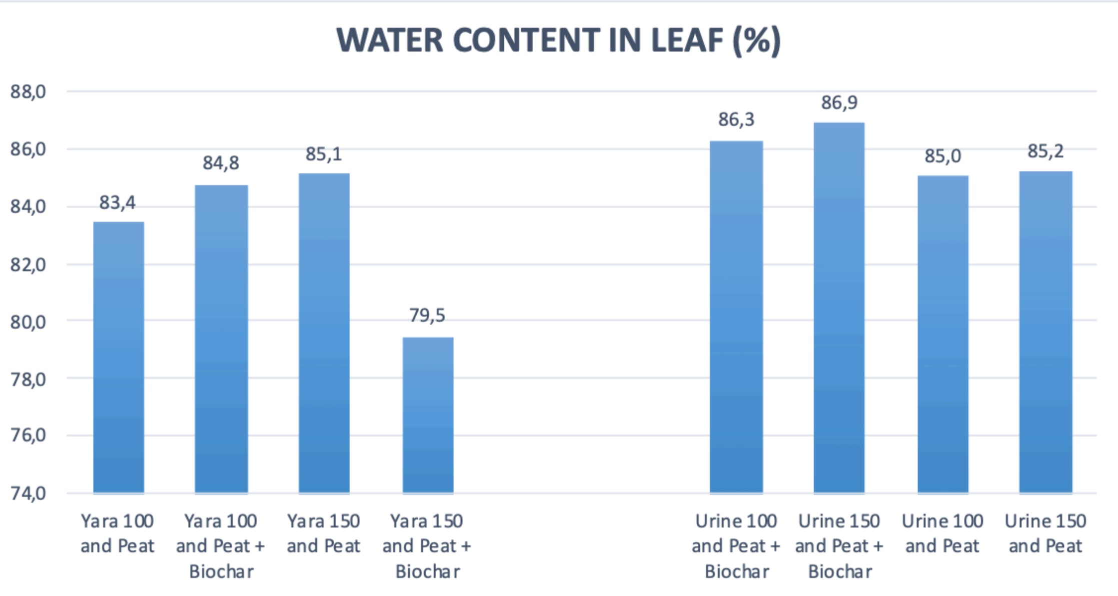


FIGURE 5. Water content in leaf

4.5 Fresh root length

Root length and root diameter are other important traits for examining nutrients and water uptake from the soil. The total root length was measured by using a special paper ruler to make the process easier and not to break the roots. As being illustrated in Figure 6 below, the average root length in each growing medium varied significantly. The longest average root length can reach around 15 cm in treatment urine 150 mg/L and peat, followed by treatment urine 100 mg/L and peat with 12,4 cm in length. There were 5 treatments had the average roots grow equally ranging from 5 - 7 cm. Only treatment Yara fertilizer 150 mg/L and peat gave the shortest root length (4,6 cm). However, the average root length is one of the methods to analyze nutrient and water uptake of the plant and it is not a standard method to conclude the relationship between root length and crop yield due to the fact that roots could be broken to some extend while harvesting and made significant difference from root lengths to root conditions (Picture 24).

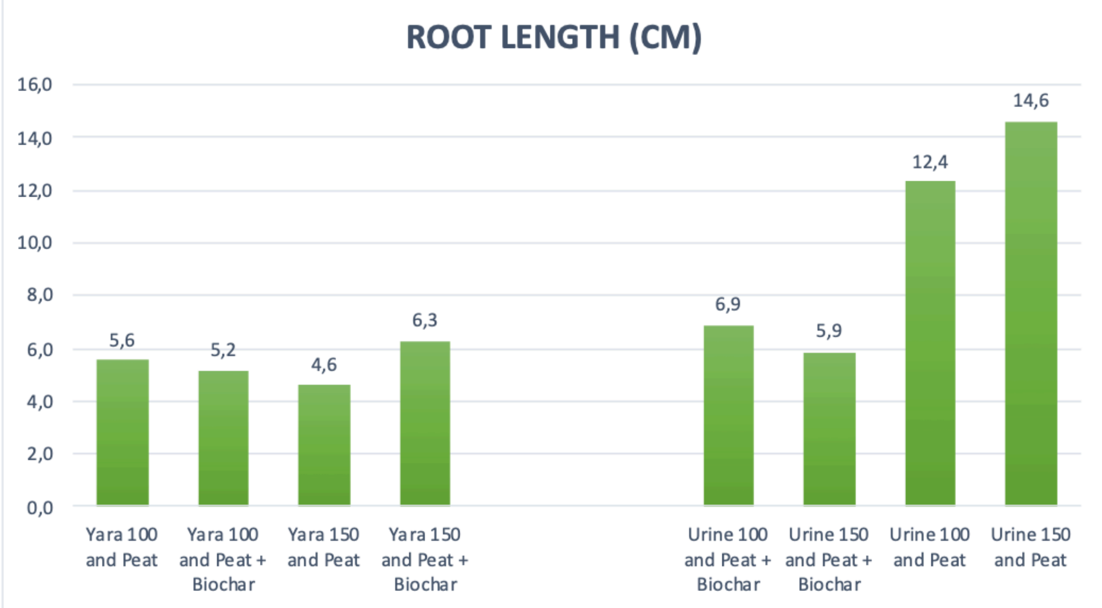


FIGURE 6. Fresh root length

PICTURE 24. Different root lengths and root conditions.

5 DISCUSSION AND CONCLUSION

5.1 The effects of nutrient types and concentrations on the yield of Swisschard

Initially, the nitrogen level of fertilization for Swiss chard was 170 kg N/ha as a reference value. The amount of human urine fertilizer and mineral Yara fertilizer were calculated based on this nitrogen demand. The fertilizers were then diluted with water into 2 different concentrations 100 mg/L and 150 mg/L before being transmitted to the irrigation system to feed the plants after 2 weeks of sowing.

The results of this BioRaki project showed a distinction between various treatments undertaken. The yield by mass of Swiss chard in Yara fertilizer was higher than that when using concentrated urine fertilizer. However, the difference was still compatible when it comes to the yield of stem and leaf which was the vital part of Swiss chard to be harvested and consumed. In other studies conducted by TAMK throughout years, for instance, Hannila's Bachelor Thesis of Cabbage and Maize grown with human urine, cow dung and mineral fertilizer in 2008, Hamdine's Bachelor Thesis of Potato and Cabbage grown with human urine, compost and mineral fertilizer in 2008, Mburu's Bachelor Thesis of Lettuce grown with human urine in 2012 and Dang's Bachelor Thesis of Barley grown with human urine and mineral fertilizer in 2019, they all figured out that the final yield mass of those plants grown with human urine could be competitive with those results grown with other types of composts or mineral fertilizers. Therefore, it came to the conclusion that the possibility and feasibility of concentrated human urine to replace mineral fertilizers in terms of nitrogen content could not be negligible.

Furthermore, the concentrations, doses and the methods used to apply nutrient on plants also play important role in the final yield mass. In this case, Swiss chard behave better results towards the 100 mg/L of fertilizer that it can accumulate higher nutrient demand and gain higher productivity. The concentration of 150 mg/L, disregarding nutrient types, seemed to be overfertilized as Swiss chard could not absorb all the nutrients from the roots and use to nourish other parts.

Besides, as mentioned in the Theory part, overfertilization, especially nitrogen fertilizer, can lead to catastrophic environmental problems as well as human health issues. Thus, it is important to avoid the excessive use of nitrogen fertilizers in order to minimize nitrates build up in soil and vegetables, without affecting product quality.

5.2 The effects of substrates on the growth and yield of Swiss chard

Substrates are recommended to be used and combined with soil to create a better growing medium, especially for this case as nitrogen fertilizers are easily evaporated. Two different types of substrates were testified in Bioraki project: peat and biochar. It is noticeable that although peat is the most widely studied and used around the world, it is considered to be a non-renewable resource and its use in the agriculture industry must be gradually decreased. On the contrary, biochar becomes increasingly approved and analyzed as peat substitute.

Both substrates consist of many beneficial features to the growth of Swiss chard such as organically rich, high water, air and nutrient retention ability, disease restraining and plant growth enhancing qualities. However, the yield mass of peat and biochar mixture was about 4 g higher than the total yield mass of peat. Therefore, in this case, it is noticeable that peat is not a good growing medium to use as a stand-alone substrate, and it is usually recommended to be mixed with other ingredients like biochar in order to achieve better moisture holding, water distribution and plant establishment.

Besides, during the growing period, there were two characteristics that the substrates (peat and mixture of peat and biochar) could have directly impacts on the plant growth. First of all, the high drainage ability which is good for Swiss chard to be grown in pots or garden. Nevertheless, in vertical farming system like Evergreen's Grow 360, this high permeability feature in addition to gravity force can cause some effects on nutrient uptake. When the core of each tower was irrigated, the water and nutrients seemed to retain best in the middle of the tower where it had the most stable retention and permeability rate. To be more specific,

in some of the growing towers, Swiss chard tended to strive stronger and faster in the middle part than the top or bottom of the tower.

The second factor which causes effect on the total yield of Swiss chard is pH. Peat moss has an acidic pH, generally in the range of 4.5, while Swiss chard tends to flourish in neutral pH about 7. Even though, peat was mixed with biochar which has pH =10, the ratio that peat contributed was still higher (7:3). Most of the nutrients (N, P and K) are available within pH 6.5 - 7.5. In highly acidic growing medium, Al, Fe and Mn can become more available and more toxic to plant while Ca, P and Mg are less available to plants. While in highly alkaline soil, P and most micronutrients become less available for plant to uptake (Miller 2016). Moreover, the pH affects how tightly nutrients are bound to soil particles. When the pH of soil is extremely low (acidic) or very high (basic), many nutrient elements become unapproachable to plants as they are no longer able to be dissolved in soil water (Crouse 2018). In this case, provided nutrients from fertilization tend to be blocked and might not reach the plant root as well as nourish the plant. For that reason, it is recommended to liming the substrates up to 3 - 6 months before planting so it can neutralize the acidity (Nathan 2017).

5.3 Conclusion

In a nutshell, Swiss chard is prone to salinity, neutral pH, wide range of temperature, average irrigation, and moisture; hence, it is well-grown in Evergreen's Grow360 indoor vertical farming system with advanced technology used to monitor and manage the whole system. In addition, Swiss chard behaves and flourished well with either mineral fertilizers or human concentrated urine and gives better results towards the 100 mg/L of fertilizer concentration which it can accumulate higher nutrient demand and gain higher productivity. Thus, it opens up a promising future for human urine to be utilized as a substitute for mineral fertilizers in an attempt to minimize the mining and manufacture process of fossil mineral resources around the world. In this experiment, biochar plays a special role in not only growing progress (moisture holding, water distribution and plant establishment) but also being as a peat substitute in the future due to its non-renewable issue.

On the other hand, this project should continue with further analysis and measurements such as the total Kjeldahl nitrogen (organic nitrogen and inorganic nitrogen compounds NH_3/NH_4^+) of the dried Swiss chard and the substrates within each tower, the salt content, chemical content as well as heavy metal content in growing substrates and dried Swiss chard. Therefore, it can draw deeper conclusion on whether the fertilization can cause any harm to consumer health and environmental related problems when Swiss chard is cultivated in Grow360 system. Moreover, human urine fertilizer should be introduced and recognized as a promising method to provide enough nitrogen for plant to absorb and a sustainable way to close the loop of nutrient recovery.

REFERENCES

Alburquerque, J. A., Salazar, P., Barrón, V. et al. 2013. Enhanced wheat yield by biochar addition under different mineral fertilization levels. Agronomy for Sustainable Development Journal. URL https://link.springer.com/article/10.1007/s13593-012-0128-3#citeas (accessed on 25.03.2020)

Atkinson, C. J., Fitzgerald, J. D., Hipps, N. A. 2010. Potential mechanisms for achieving agricultural benefits from biochar application to temperate soils: a review. Plant and Soil Journal. URL https://link-springer-com.libproxy.tuni.fi/article/10.1007/s11104-010-0464-5 (accessed on 27.03.2020)

Canadian Sphagnum Peat Moss Association. Webpage. URL https://peatmoss.com/peat-moss-organisations/canadian-sphagnum-peat-moss-association/ (accessed on 20.03.2020)

CARBOFEX Oy. Webpage. URL https://www.carbofex.fi/ (accessed 05.03.2020)

Carroll, J. 2020. Peat Moss and Gardening - Information About Sphagnum Peat Moss. Gardening Know How Journal. Blogpost. URL https://www.gardeningknowhow.com/garden-how-to/soil-fertilizers/peat-moss-information.htm (accessed on 30.04.2020)

Cho, R. 2013. Phosphorus: Essentual to Life - Are We Running Out. Blogpost. URL https://blogs.ei.columbia.edu/2013/04/01/phosphorus-essential-to-life-are-we-running-out/ (accessed 16.06.2020)

Crouse, D. A. 2018. Soils and Plant Nutrients, Chapter 1. In: K.A. Moore, and. L.K. Bradley (eds). North Carolina Extension Gardener Handbook. URL https://content.ces.ncsu.edu/extension-gardener-handbook/1-soils-and-plant-nutrients#section_heading_7240 (accessed 20.06.2020)

Dang, V. T. 2019. Nitrogen Concentration in Barley and Soil with Different Fertilizer Treatments. Bachelor’s thesis. Tampere University of Applied Sciences.

Tampere, Finland. URL https://www.theseus.fi/handle/10024/168859 (accessed 10.05.2020)

Decree of the Ministry of Agriculture and Forestry on Fertilizer Products. 2013. Annex IV. Harmful Substances, Organisms and Contaminants in Fertilizer Products. URL https://mmm.fi/documents/1410837/2061117/MMMa_24_2011_lannoitevalmisteasetus_EN.pdf/c49d5007-0b00-431e-b5ca-53ecdf236c3a/MMMa_24_2011_lannoitevalmisteasetus_EN.pdf (accessed on 15.05.2020)

EIP-AGRI Focus Group on Nutrient Recycling. 2017. Final meeting report. URL chrome-extension://ohfgljdgelakfkefopgklcohadegdpjf/https://ec.europa.eu/eip/agriculture/sites/agri-eip/files/eip-agri_fg_nutrients_recycling_final_report_2017_en.pdf (accessed 20.06.2020)

European Biochar Foundation. 2012. European Biochar Certificate - Guidance for a Sustainable Production of Biochar. Arbaz, Switzerland. Version 6.1 of 19th June 2015. URL http://www.european--biochar.org/en/download (accessed 20.04.2020)

Evergreen Farm Oy. Webpage. URL https://www.evergreenfarm.eu/ (accessed on 25.02.2020)

Global Dry Toilet Association of Finland. 2017. The Use of Urine as Fertilizer. Global Dry Toilet Association of Finland, Tampere Publisher. URL http://www.huussi.net/wp-content/uploads/2013/06/Manual-3_ENGLISH.pdf (accessed on 27.04.2020)

Grunbaum, M., 2010. Gee Whiz: Human Urine Is Shown to Be an Effective Agricultural Fertilizer. Scientific American. URL https://www.scientificamerican.com/article/human-urine-is-an-effective-fertilizer/ (accessed 04.04.2020)

Gupta, N., Debnath, S., Sharma, S., Sharma, P. & Purohit, J. 2017. Role of Nutrients in Controlling the Plant Diseases in Sustainable Agriculture. Agriculturally

Important Microbes for Sustainable Agriculture Book. URL https://www.researchgate.net/publication/319934097_Role_of_Nutrients_in_Controlling_the_Plant_Diseases_in_Sustainable_Agriculture/citations (accessed on 12.04.2020)

Hamdine, S. 2008. Heavy metal traces in potatoes and cabbage fertilized with human urine and composted faeces. Bachelor's thesis. Tampere University of Applied Sciences. Tampere, Finland. URL https://www.theseus.fi/handle/10024/8150 (accessed on 10.05.2020)

Hannila, A. 2008. Evaluation of urine as a fertilizer for bread and cabbage production in Kaloko village, Zambia. Bachelor's thesis. Tampere University of Applied Sciences. Tampere, Finland. URL https://www.theseus.fi/handle/10024/8422 (accessed on 12.05.2020)

Isherwood, K. F. 2000. Fertilizer Use and the Environment. International Fertilizer Industry Association Publisher. Book. Paris, France. URL https://www.fertilizer.org/images/Library_Downloads/2000_ifa_unep_use.pdf (accessed on 10.03.2020)

Jaatinen, S. 2016. Characterization and Potential Use of Source-Separated Urine. Tampere University of Technology. Publication. Vol 1391. URL https://tutcris.tut.fi/portal/en/publications/characterization-and-potential-use-of-sourceseparated-urine(6158d7ad-245a-4c2b-9809-68e788a1de7c).html (accessed on 12.04.2020)

Lehmann, J., 2007. Bioenergy in the black. Frontiers in Ecology and the Environment 5, 381–387. URL https://esajournals.onlinelibrary.wiley.com/doi/full/10.1890/1540-9295%282007%295%5B381%3ABITB%5D2.0.CO%3B2 (accessed 18.04.2020)

Lehmann, J., Joseph, S., 2015. Biochar for Environmental Management: Science, Technology and Implementation. Routledge, London, United Kingdom.

Book. 2nd edition. URL https://ebookcentral.proquest.com/lib/tampere/reader.action?docID=1975245 (accessed on 20.04.2020)

Lehmann, J., Rillig, M.C., Thies, J., Masiello, C.A., Hockaday, W.C., Crowley, D., 2011. Biochar effects on soil biota – A review. Soil Biology and Biochemistry, 19th International Symposium on Environmental Biogeochemistry 43, 1812–1836. https://doi.org/10.1016/j.soilbio.2011.04.022 (accessed 20.04.2020)

Mahr, S. 2012. Swiss Chard. Master Gardener Program. Blogpost. URL https://wimastergardener.org/article/swiss-chard/ (accessed 24.03.2020)

Maynard, D.N., Hochmuth, G.J., Knott, J.E., 2007. Knott's handbook for vegetable growers. John Wiley & Sons Inc Publisher. New York, United States. Book. 5th edition (accessed on 10.03.2020)

Mburu, C. 2012. Urine as a fertilizer for lettuce grown in greenhouse conditions. Bachelor's thesis. Tampere University of Applied Sciences. Tampere, Finland. URL https://www.theseus.fi/handle/10024/48768 (accessed 12.05.2020)

Miceli, A., Miceli, C., 2014. Effect of Nitrogen Fertilization on the Quality of Swiss Chard at Harvest and during Storage as Minimally Processed Produce. Journal of Food Quality 37, 125–134. URL https://doi.org/10.1111/jfq.12073 (accessed on 20.03.2020)

Miller, J. O. 2016. Soil pH Affects Nutrient Availability. University of Marryland Extension.URLhttps://www.researchgate.net/publication/305775103_Soil_pH_Affects_Nutrient_Availability (accessed 20.06.2020)

Mosier, A. R., Syers, J. K. & Freney, J. R. 2004. Agriculture and the Nitrogen Cycle. Book. Island Press Publisher. 2nd edition. URL https://ebookcentral.proquest.com/lib/tampere/reader.action?docID=3317459 (accessed on 30.04.2020)

Nathan, M. V. 2017. Missouri Master Gardener Core Manual. University of Missouri Extension. URL https://extension2.missouri.edu/mg4#:~:text=Nutrient%20cations%20in%20the%20soil,per%20100%20grams%20of%20soil. (accessed 21.06.2020)

Olaria, M., Nebot, J.F., Molina, H., Troncho, P., Lapeña, L., Llorens, E., 2016. Effect of different substrates for organic agriculture in seedling development of traditional species of Solanaceae. Spanish Journal of Agricultural Research Vol 14. URL https://doi.org/10.5424/sjar/2016141-8013 (accessed on 15.05.2020)

Prahdan, S. K. 2010. Yield and quality of vegetables fertilized with human urine and wood ash. University of Eastern Finland Publisher. Dissertations in Forestry and Natural Sciences. Kuopio, Finland. URL https://epublications.uef.fi/pub/urn_isbn_978-952-61-0062-3/urn_isbn_978-952-61-0062-3.pdf (accessed on 20.04.2020)

Raude, J. M. 2019. Towards Sustainable Development Goals: The Nexus of Water, Food and Energy. Irrigated Agriculture, A Case Study in Kenya and Uganda. Internal Lecture. URL chrome-extension://ohfgljdgelakfkefopgklcohadegdpjf/https://moodle.jyu.fi/pluginfile.php/348424/course/section/47299/Raude_PDF.pdf (accessed 15.06.2020)

Richert, A., Gensch, R., et al. 2010. Practical Guidance on the Use of Urine in Crop Production. Stockholm Environment Institute. Stockholm, Sweden. URL http://www.ecosanres.org/pdf_files/ESR2010-1-PracticalGuidanceOnTheUseOfUrineInCropProduction.pdf (accessed on 15.04.2020)

Sacan, O., Yanardag, R., 2010. Antioxidant and antiacetylcholinesterase activities of chard (Beta vulgaris L. var. cicla). Food and Chemical Toxicology 48, 1275–1280. URL https://doi.org/10.1016/j.fct.2010.02.022 (accessed on 27.03.2020)

Schiller, N., 2019. How to Plant and Grow Swiss Chard. Gardener's Path. URL https://gardenerspath.com/plants/vegetables/grow-swiss-chard/ (accessed 24.03.2020)

Simpson, R. 2019. Phosphorus: A finite resource essential for life, critical for agriculture and food security. Blogpost. URL https://ecos.csiro.au/phosphorous/ (accessed 16.06.2020)

Viskari, E.L. Urine as fertilizer. Internal lecture. University of Jyvaskyla. URL https://moniviestin.jyu.fi/ohjelmat/science/bioenv/ymparistotiede/nexus/urine-as-fertilizer-experiments (accessed 05.04.2020)

Wilson, K. 2014. How biochar works in soil. The Biochar Journal. Blogpost. URL https://www.biochar-journal.org/en/ct/32-How-biochar-works-in-soil (accessed 06.04.2020)

Yara Suomi. Yara FERTICARE 4-17-24 product. Webpage. URL https://www.yara.fi/lannoitus/lannoitteet/muut-tuotteet/ferticare--4-17-24/ (accessed on 10.04.2020)

Yara Suomi. YaraTera CALCINIT product. Webpage. URL https://www.yara.fi/lannoitus/lannoitteet/yaratera/yaratera-calcinit/ (accessed on 10.04.2020)