Sveriges lantbruksuniversitet
Swedish University of Agricultural Sciences

Faculty of Landscape Architecture, Horticulture and Crop Production Science

Urban Farming: Production comparison of Basil and Oak Leaf lettuce in two hydroponic growing systems

- An industrial collaborated study in Sweden

Omer Hafeez Malik

Independent project: 30 hp
Swedish University of Agricultural Sciences, SLU
Department of Biosystems and Technology
Master´s Thesis in Horticultural Science
Alnarp 2020

Urban Farming: Production comparison of Basil and Oak Leaf lettuce in two hydroponic growing systems

Omer Hafeez Malik

Supervisor: Karl-Johan Bergstrand, Department of Biosystems and Technology, SLU

Co-supervisor: Andreas Dahlin, CEO, Swegreen

Examiner: Anna Karin Rosberg, Department of Biosystems and Technology, SLU

Credits: 30 hec
Project level: A2E, second cycle, Master's thesis
Course Title: Master's thesis in Horticultural Sciences
Course code: EX0947
Program/Education: Horticultural Sciences, Master's Program

Place of Publication: Alnarp, Sweden
Year of Publication: **2020**
Online publication: http://stud.epsilon.slu.se
Keywords: Hydroponics, *Lactuca sativa, Ocimum basilicum,* Precision farming, vertical farming

Acknowledgements

I humbly express my thanks to Almighty Allah (The Most Magnificent, The Most Merciful). All praises to the beacon of knowledge, Prophet Muhammad (peace and blessings be upon him), for enlightening my vision and broadening my scope. A special thanks to my family for their unwavering support and words of encouragement to complete this study.

I am very thankful to my supervisor, Karl-Johan Bergstrand, Department of Biosystems and Technology, SLU, co-supervisor, Andreas Dahlin, (CEO, Swegreen) and Sepehr Mousavi, Chief Innovation Officer, Swegreen for their guidance, time, support, and suggestions to complete this study and write up of this thesis. A very special thanks to the staff at Swegreen especially Joakim, Yulya, Adam and Daniel for their support and to make available all the facilities needed to perform this study.

I gratefully acknowledge the Partnerskap Alnarp for their financial support for my travel to research facility at Swegreen, Stockholm.

(Omer Hafeez Malik)

Abstract

The modern agriculture of the world is facing huge challenges in terms of increasing scarcity of natural resources such as water and land. The increase in global population is not only enabling in expansion of big cities but also raising questions of accommodating and feeding this amount of population. A global food security risk and pressure on existing natural resources are well expected in coming years. The use of chemicals and fertilizers to increase food production from the same land area is posing serious risks to human health and environment by increasing the emission of greenhouse gases. In this intricate scenario, indoor urban farming is gaining popularity because of many coupled advantages and benefits. Vertical farming is now being considered a means to grow and supply crops to cities. Advanced types of hydroponics and aquaponics are being tested and used to increase the per square meter production of crops. The controlled climate conditions enable the production of crops irrespective of outside weather conditions. The trend of conversion of abandoned buildings, warehouses, basements etc. into indoor food production plant factories is increasingly rapidly. This type of farming also allows for chemical free produce.

SweGreen AB is a local Swedish company based in Stockholm with its farm located in the basement of an office building. The company is already in the stage of commercial production of leafy greens. In order to further streamline and strengthen the production processes, company is adopting new and advanced hydroponic based vertical production systems. This study was aimed to investigate the production of basil and oak leaf lettuce in two different types of growing systems i.e. Testbed vertical layer system and zip grow tower system. The vertical layer systems are reported to grow more plants per square meter and more production.

The results showed that plants grown in vertical layer test bed system tend to have more plant height, leaf numbers, higher chlorophyll contents and lower leaf temperature than the zip grow system. The energy efficiency is no doubt improved in vertical farming systems but the high costs of energy usage and its effect on environment must be taken into account. The fresh weight of plants grown in test bed system was also higher than the ones grown in zip grow system. Further studies are needed to investigate the crop production potential on commercial scale with precision farming, integration of AI (artificial intelligence) and IOT (internet of things) along with complete control on factors like temperature, humidity, CO_2 levels, light and nutrients.

Keywords: Hydroponics, *Lactuca sativa*, *Ocimum basilicum*, Precision farming, Vertical farming

Summary

The current study was performed in order to investigate the feasibility of indoor farming system and to compare two different types of hydroponic growing systems i.e. Zipgrow towers (ZG) and flat vertical layer test bed (TB) for the production of two selected leafy greens Basil (*Ocimum basilicum*) and lettuce (*Lactuca sativa*).

Overall, test bed vertical layer system showed better results when it came to the growth and production of both crops. The plant height was recorded to be higher in both crops grown in TB system as compared to ZG system. Leaf count and leaf dimensions were also found to be greater in the crops grown in TB system. The average leaf temperature of crops in TB system was comparatively less than the crops grown in TB system which can be helpful to save the plants from stress. The leaf chlorophyll contents were also found to be higher in plants grown in TB system. The energy efficiency of crops grown in the indoor farming systems was also calculated. The farm is successfully using the free energy from bed rock and returning back the energy to system in the form of cooling to the building in which farm is located. Calculations of energy use efficiency showed that the land use efficiency was better than conventional lettuce production in Sweden.

Future recommendations are to test the vertical layer test bed system on large commercial scales with the integration of artificial intelligence and internet of things to streamline the path for a system which can be remotely controlled and be able to modify the environmental conditions and nutritional input according to the need of plants and prevailing farm conditions. The integration of smart technologies with indoor vertical farming systems with more research in optimizing and profiling light spectrum and management strategies on a varied crop types other than leafy greens is also needed to be addressed in future.

Contents

Chapter 1: Introduction

The world production of crops is facing hard challenges because of unpredicted weather, climate change, global warming, water scarcity and lack of sufficient arable land for cultivation (Ramin Shamshiri et al., 2018). The rapid increase in world population and a shift of population to urban cities has posed serious food security risks for future generations (Langelaan et al., 2013). It is estimated that the world population in 2050 will be around 9 billion and the growing trend of urbanization will lead to the addition of another two-thirds of the population to settle down in cities in the next thirty years (Kozai et al., 2019; Benke & Tomkins, 2017). The main issues related to the rapid urbanization are maintenance of sustainable supply of food, intensive use of existing resources (e.g. water, energy and land) and deterioration of the surrounding environment (Carey et al., 2016). In order to feed the growing population in cities, intensive use of fresh water and energy resources for food production are negatively contributing to climate change by adding CO_2 and other greenhouse gas emissions (Avgoustaki and Xydis, 2020).

To cater the problem of food supply/security and decrease the environmental impact of conventional food production, indoor farming has gained attention as a sustainable solution to solve the problem of food production and supply in big cities. It is now more than ever necessary to design and apply innovative growing techniques in indoor environments. When plants are grown conventionally in open fields, yield and quality of produce is subjected to weather conditions (Quinn, 2017). The risk of diseases and pest invasion is also at its greatest. Use of chemicals to control the pests and diseases brings other challenges and questions. Vertical farming can and is offering a completely new area of social service in big cities which are subjected to various environmental, economic, and social challenges. Among vertical farming systems, the revolutionary idea of Controlled Environment Urban Food Production (CEUFP), using Artificial Intelligence (AI) aided hydroponics assisted vertical farming systems, is increasingly being adopted in the developed world to not only feed the urban population but also to reduce the impact of climate change. These system uses 70-90% less water than conventional systems for growing different kinds of greens (Avgoustaki and Xydis, 2020). In CEUFP, smart integration of latest technologies such as artificial intelligence and IoT (Internet of things) are used to smartly control the factors such as light, water, CO_2, temperature and humidity to sustainably grow green leafy vegetables. Use of image processing and vision diagnostics and smart instruments to measure the plant growth and photosynthetic activity has paved way for nondestructive analysis methods. The CEUFP integrated vertical farming system of producing green vegetables in limited spaces by using vertically stacked layers, has high potential to solve the problem of sustainable supply of fresh food to cities on a daily basis (Avgoustaki and Xydis, 2020). It is a sustainable way of cultivation, and it helps prevent climate change, since the cultivation does not produce any agricultural runoff and wastes (Quinn, 2017). The outdoor production of leafy greens in open field differ in production and value because of unpredictable environmental circumstances, soil fertility and many other factors as compared to their indoor production using vertical farming (Lages Barbosa et al., 2015). Indoor farming can provide maximum and quality production per square meter due to control over factors required for plant growth (Despommier, 2011). Ready to Eat (RTE) salads have become popular in daily diet of people in recent years (EC, 2005). The minimal processing of RTE salads and leafy greens helps them in maintaining their nutrition and flavor. There has been increase in the demand of fresh, crispy, tasty and safe RTE leafy greens among consumers and restaurants in big cities (Ragaert et al., 2007). A major risk associated with the consumption of leafy greens coming from open field cultivation is the increased incidence of food borne pathogens such as *E. Coli* and related outbreaks (Manzocco et al., 2011, Alsanius et al., 2019). Urban food production has enabled to provide fresh leafy greens to the people living in big cities (Despommier, 2011). More indoor farms are being developed in urban cities, with a focus of using soilless cultivation systems such as hydroponics, as they reduce the risk of contamination caused by soil, chemicals, water and by fertilizers usage (Tomasi et al., 2015). The direct control on nutrients, water, light, CO_2, temperature and humidity enables safe, healthy, uniform and predictable production (Frezza et al., 2005, Gullino et al., 2019).

Many companies have step forward in this business and are commercially producing leafy greens on a large scale. One of the newly emerging companies is SweGreen, which is an innovation and technology urban farming company based in Stockholm, Sweden. The farm is located in the basement of a building in Stockholm. The farm is built on a unique concept based on industrial ecosystem services mimicking the nature indoors. This study was made on the concept of precision agriculture in order to feed data to artificial intelligence AI database. The company is integrating smart vertical farming solutions into real-estate properties by providing circular energy-waste-water and carbon-absorbing systems, which is providing locally grown and high quality green vegetables with minimal environmental impact by using digitalization, Internet of Things (IoT), data science and artificial intelligence (AI) as enabling tools to offer advanced energy recycling solutions and exchange of carbon dioxide and oxygen for production of fresh crops.

This study is aimed to investigate the feasibility of indoor farming systems, and the effect of two different types of vertical farming systems i.e. Zipgrow towers and vertical layers on the production of Basil (*Ocimum basilicum*) and lettuce (*Lactuca sativa*), Red Oak leaf lettuce which are well-known herbs used in daily diet. The hypothesis of this study was that the quality, overall growth, and yield of basil and lettuce will be better in vertical layer test bed system as compared to zip grow towers.

Chapter 2: Materials and Methods

2.1. Plant materials and growing conditions

The current study was performed in order to compare two different types of hydroponic growing systems i.e. Zipgrow towers (ZG) and flat vertical layer test bed (TB) for the production of two selected leafy greens, farm during September 22, 2020 to October 30, 2020. A three-story test bed (TB) system in an area of 2.8 x 2.8 x 0.8 m was developed to investigate the growth of selected leafy greens in comparison with reference Zipgrow towers already in use on the farm. Zipgrow towers are modular growing towers normally used for high density indoor vertical farming farms (Team, 2020). The middle layer of testbed was used for this experiment.

Carefully selected healthy seeds of Basil (*Ocimum basilicum*) and Oak Leaf Lettuce (*Lactuca sativa L.*) were selected for germination. Basil seeds were sourced from Semenco AB, Asmundtorp, Sweden and Ekblad seeds were sourced from Olssons Frö AB, Helsingborg, Sweden. The germination trays with plug dimensions (3.6 x 3.6 x 4.0 cm) were sourced from GRODAN company (Hedehusene, Denmark). The trays were soaked in 3% hydrogen peroxide solution for 30 minutes for disinfecting the plugs. After 30 minutes, when plugs had absorbed moisture, the trays were moved out of water and pressed slightly to remove extra dripping water. One basil seed and one Ekblad seed per plug were sown in each plug. One seedling tray each for both leafy greens were made. The trays were placed in germination chamber at 24±1°C and 70% RH. The seeds started to germinate in two days and after three days, the trays were then shifted to a nursery chamber at the same temperature and humidity. After 14 days, the plugs were transplanted to prototype vertical layer test bed and Zipgrow towers. Plant x Plant distance for basil was maintained as 16 cm and for Ekblad it was maintained as 18 cm. Three rows each with six plants were maintained in test bed and zip grow towers for both leafy greens.

2.2. Nutrient Solution

The nutrient recipe solution consisted of two stock solutions. Stock solution 1 consisted of macronutrients and stock solution 2 consisted of micronutrients. Tank 3 comprised of calcium carbonate to stabilize pH. UV filters are installed to prevent spreading of infectious microorganisms in the system. The nutrient flow for vertical layer bed was maintained at 12 L/h and for zip grow towers it was maintained at 4 L/h. The reason for less flow is because of presence of substrate in ZG towers which keeps moisturized unlike in flatbed. The complete detail of nutrient recipe is attached in appendix.

2.3. Temperature, humidity, CO_2 and light

The overall temperature and humidity in the facility was set on 24°C and 70% RH. The CO_2 level was maintained on 470 ppm. Normally, CO_2 is provided by the building occupants through ventilation system. Due to Covid-19, most of the people normally located in the building were working from home so a drastic decline of CO_2 was observed. During this decline, supplementary CO_2 was injected into the system. A sensor controlled this CO_2 injection, and it measures one time/minute. The supplement starts at 380 ppm and turned off at 550 ppm. LED lights were used 18 hours per day to provide lights for the plants. The distance of plants from the light source was maintained at 30 cm in both production systems. The light intensity was set on 400 µmol/m^2/s. (Fig. 1) The light intensity was measured by UPRtek PAR200 Quantum Spectrophotometer by placing it above plant canopy.

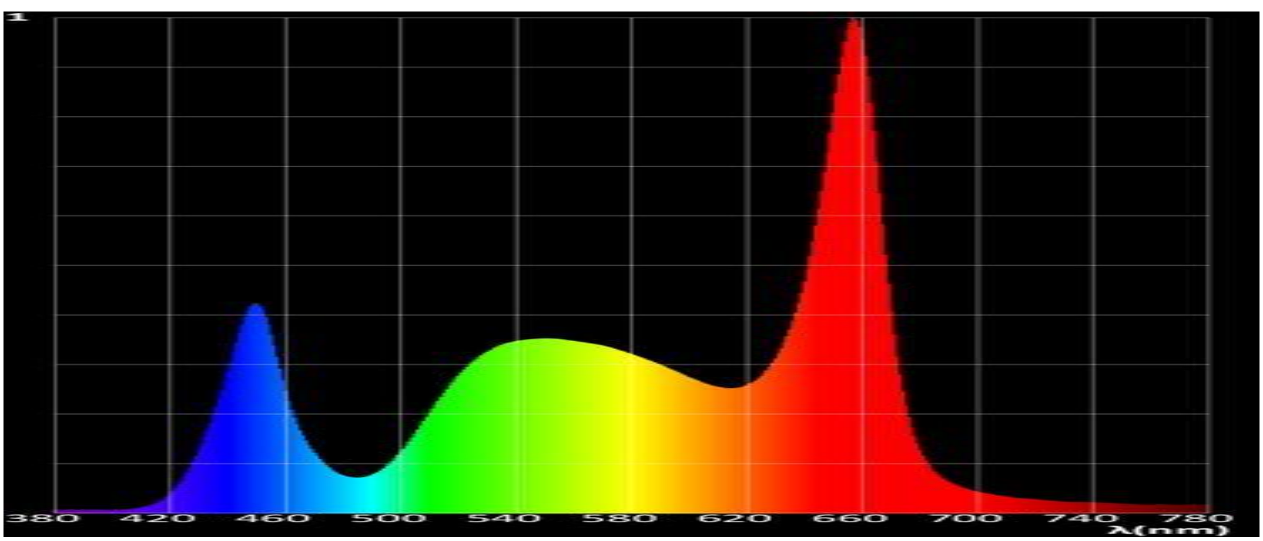

Fig. 1. Light spectral distribution

2.4. Energy usage per square meter of cultivation area

The energy used by nutrient pump was measured and distributed on the effected growing area 150 m^2. The energy used by LEDs was measured value on the two luminaries (flat system) and distributed on the effected growing area. The energy used by ventilation system was measured and distributed on the effected growing area 600 m^2.

2.5. Data Collection and Measurement

The data was recorded and measured for different parameters including plant height, leaf numbers, leaf length & width, leaf temperature and leaf chlorophyll contents weekly after transplantation day to the final harvesting day.

2.5.1. Physical Parameters

- Plant Height (cm)
- Leaf Numbers (cm)
- Leaf Length & Width (cm)

A representative leaf of medium size was selected for measuring the leaf dimensions per plant.

- Leaf temperature (°C)

Leaf temperature was measured with the help of infrared thermometer (Raytec Raynger Raytec, Santa Cruz, CA USA)).

- Leaf Chlorophyll Content

  Leaf chlorophyll value was recorded on a representative leaf of medium size per plant by a chlorophyll meter (MC-100 Apogee Instruments, Logan, UT USA).

- Fresh & Dry weight of plants (g)

  Six plants of each leafy green from two growing systems were harvested along with roots. The substrate was carefully removed from roots. The weight of fresh plant was taken and then placed in drying oven at 60°C for two days. The weight of the dried plants was then recorded.

2.6. Experimental Design

The experiment was set as completely randomized block design with two factors i.e. two hydroponic growing systems and two crops. There were three replications per crop in each growing system. Each replication contained six plants.

2.7 Statistics and calculations

The experimental design was CRBD factorial. The data were subjected to analysis of variance using Statistica software (TIBCO Software Inc., Palo Alto, CA USA) and treatment means were compared using Least Significance Difference (LSD) Test (Steel et al., 1997).

The energy usage per plant and per kg of fresh harvest was calculated in Joule. The functional unit of m^2 photovoltaic (PV) panels was introduced to describe land use efficiency. The energy efficiency of the production was calculated as

$$\text{Efficiency} = (\text{energy in produce})/(\text{energy used for the production}) \qquad (1)$$

Chapter 3: Results

3.1. Plant Height

The analysis of variance showed that plant height was significantly affected by two growing systems i.e. ZipGrow (ZG) and Test bed (TB) and crop type. The crops grown in TB gained more height as compared to the crops grown in ZG system (Fig. 3.1). A continuous increase in plant height was observed for both crops during the cropping period. The maximum height of basil and lettuce plants grown in TB during this study was found to be 25 cm and 13 cm respectively. The interaction between the growing systems and crops was found non-significant.

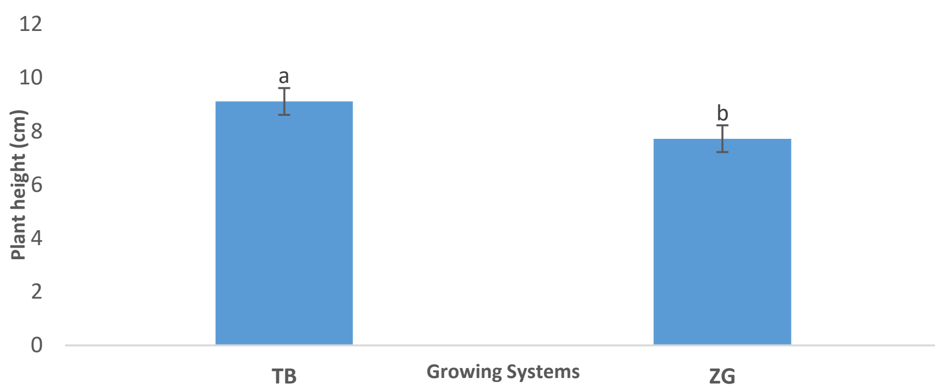

Fig. 3.1. Effect of two hydroponic growing systems i.e. test bed (TB) and Zipgrow (ZG) towers on average plant height (cm) of two leafy greens basil (*Ocimum basilicum*) and lettuce (*Lactuca sativa*).

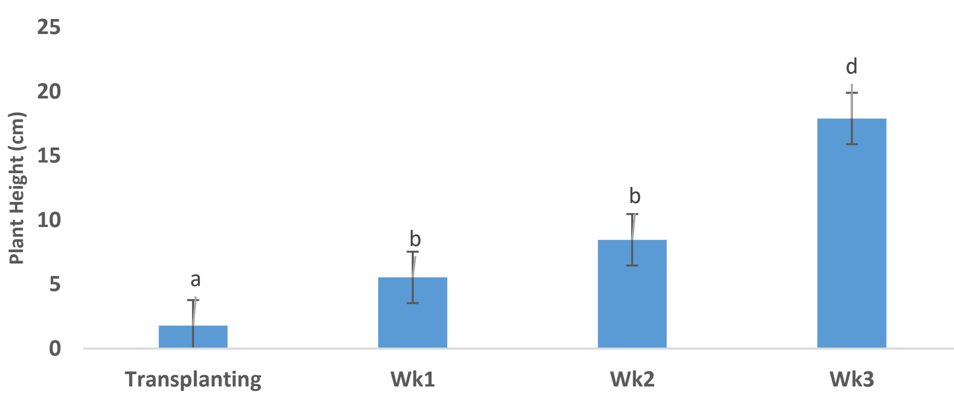

Fig. 3.2. Average plant height (cm) of of two leafy greens basil (*Ocimum basilicum*) and lettuce (*Lactuca sativa*) grown in two hydroponic growing systems i.e. test bed (TB) and Zipgrow (ZG) towers after one week (Wk1), two weeks (Wk2) and three weeks (Wk3) of tranplanting.

3.2. Leaf Numbers, Leaf Length and Leaf Width

The analysis of variance showed an overall significant relationship between leaf numbers, length, width and growing systems. A greater number of leaves was found in crops grown in TB as compared to crops in ZG (Fig. 3.3). The length and width of leaves of crops grown in TB was found to be higher as compared to the leaves of crops grown in ZG. The leaf numbers along with their length and width was also found to increase with the growth period (Fig. 3.4). During this study, the average number of basil and lettuce leaves noted per plant were 13 and 9 respectively. The leaf length of basil and lettuce was 6.0 cm and 8.3 cm and leaf width was 4.5 cm and 9.3 cm respectively. The interaction between leaf count and dimensions with the growing systems was found to be significant.

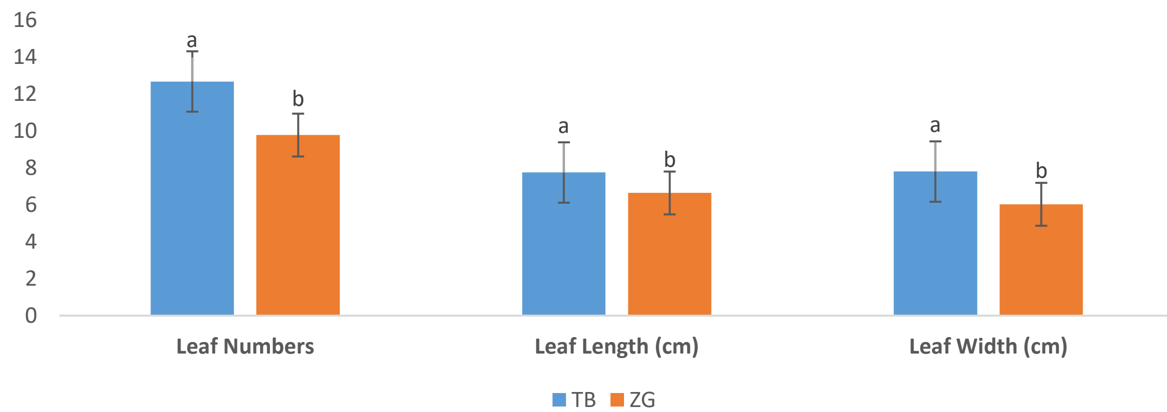

Fig. 3.3. Effect of two hydroponic growing systems i.e. test bed (TB) and Zipgrow (ZG) towers on average leaf numbers, leaf length (cm) and leaf width (cm) of two leafy greens basil (*Ocimum basilicum*) and lettuce (*Lactuca sativa*).

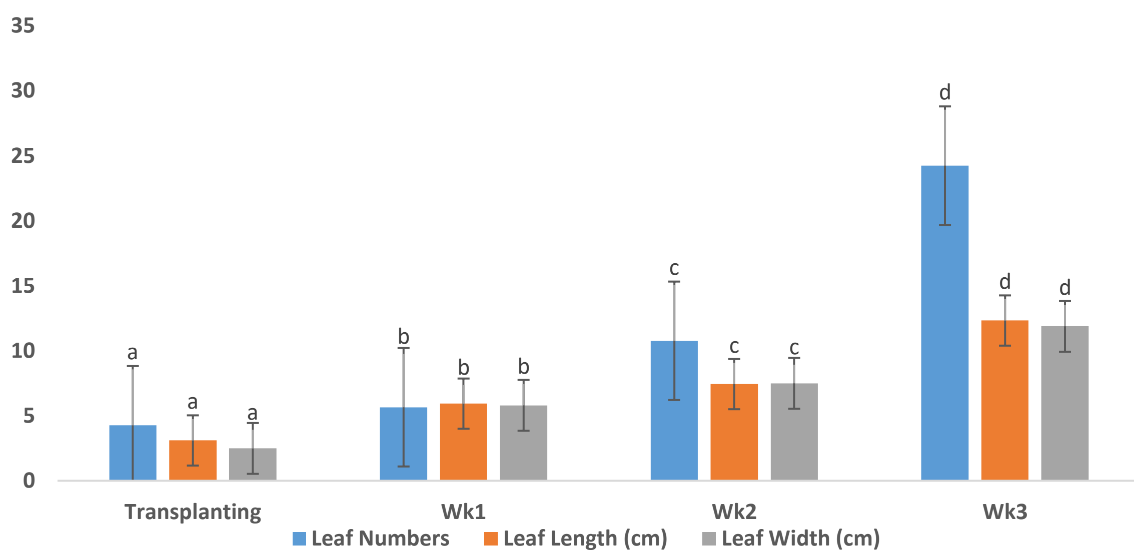

Fig. 3.4. Average leaf numbers, leaf length (cm) and leaf width (cm) of of two leafy greens basil (*Ocimum basilicum*) and lettuce (*Lactuca sativa*) grown in two hydroponic growing systems i.e. test bed (TB) and Zipgrow (ZG) towers after one week (Wk1), two weeks (Wk2) and three weeks (Wk3) of tranplanting.

3.3. Leaf Temperature

The statistical analysis showed that leaf temperature was significantly affected by the choice of growing systems (Fig. 3.5). The leaf tempeatures of crops grown in TB was less than that of the crops growing in ZG system. The leaf temperature was found to increase in the first week after transplantaion and after that it dropped in the coming week (Fig. 3.6). An increase in leaf temperature was found in last week of production. The overall leaf temperature of both crops was found lower than the ambient air temperature (22.85°C) in the farm. The interation effect of cropping systems and crops on leaf temperature was also found significant (Fig. 3.7).

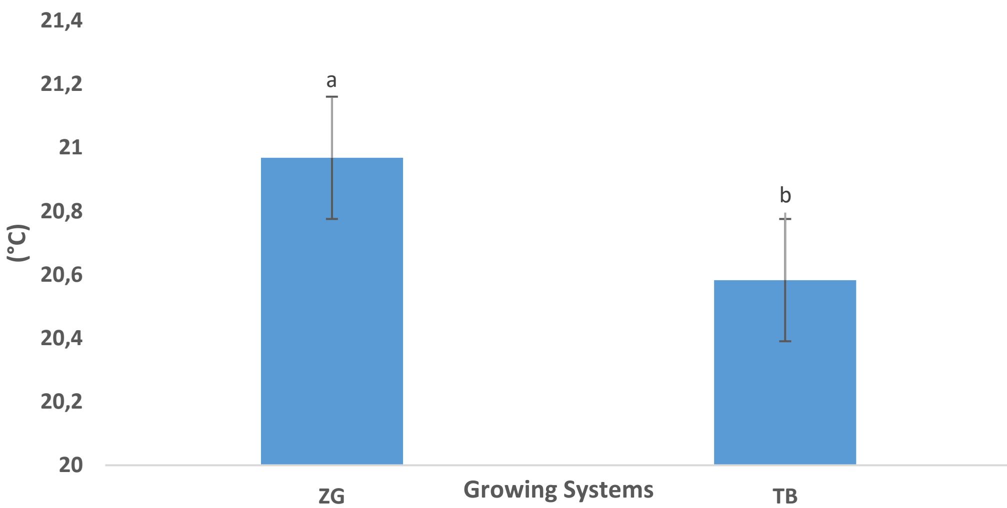

Fig. 3.5. Effect of two hydroponic growing systems i.e. test bed (TB) and Zipgrow (ZG) towers on average leaf temperature (°C) of two leafy greens basil (*Ocimum basilicum*) and lettuce (*Lactuca sativa*).

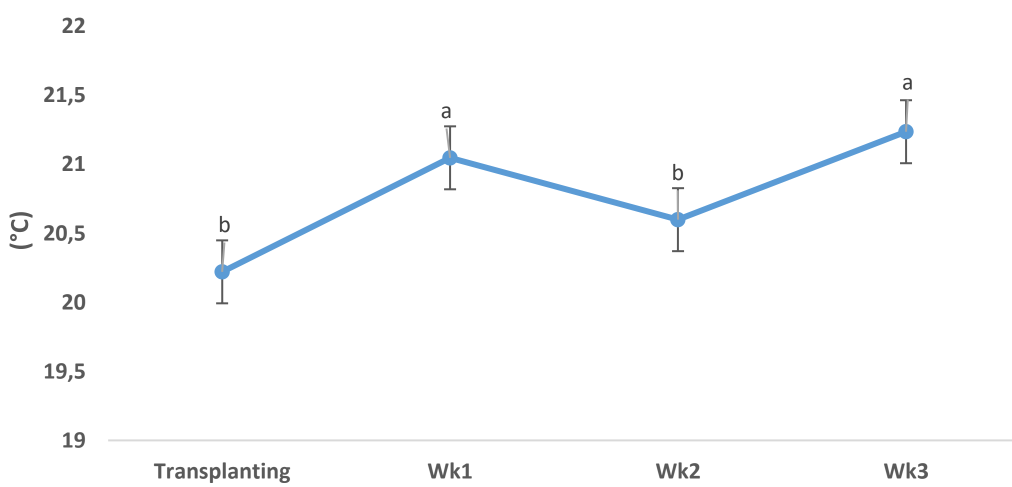

Fig. 3.6. Average leaf temperature (°C) of of two leafy greens basil (*Ocimum basilicum*) and lettuce (*Lactuca sativa*) grown in two hydroponic growing systems i.e. test bed (TB) and Zipgrow (ZG) towers after one week (Wk1), two weeks (Wk2) and three weeks (Wk3) of tranplanting.

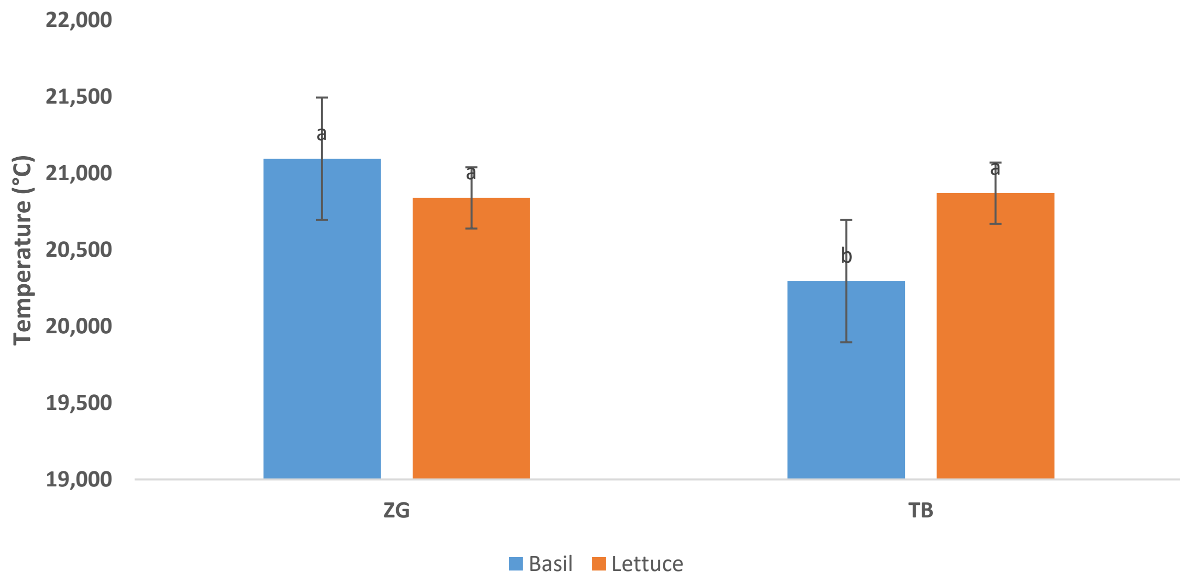

Fig. 3.7. Effect of two hydroponic growing systems i.e. test bed (TB) and Zipgrow (ZG) towers on average leaf temperature (°C) of two leafy greens basil (*Ocimum basilicum*) and lettuce (*Lactuca sativa*).

3.4. Chlorophyll Contents

The analysis of variance showed that growing systems significantly affected the leaf chlorophyll contents of growing crops (Fig. 3.8). The leaf chlorophyll contents of crops grown in TB system was found to be more than the crops grown in in ZG. The chlorophyll contents of leaves were also found to increase with the growing period with maximum on final harvesting day and least on the day of transplantation (Fig. 3.9). The overall interaction between the growing systems and two crops was also found to significantly affect the leaf chlorophyll contents (Fig. 3.10).

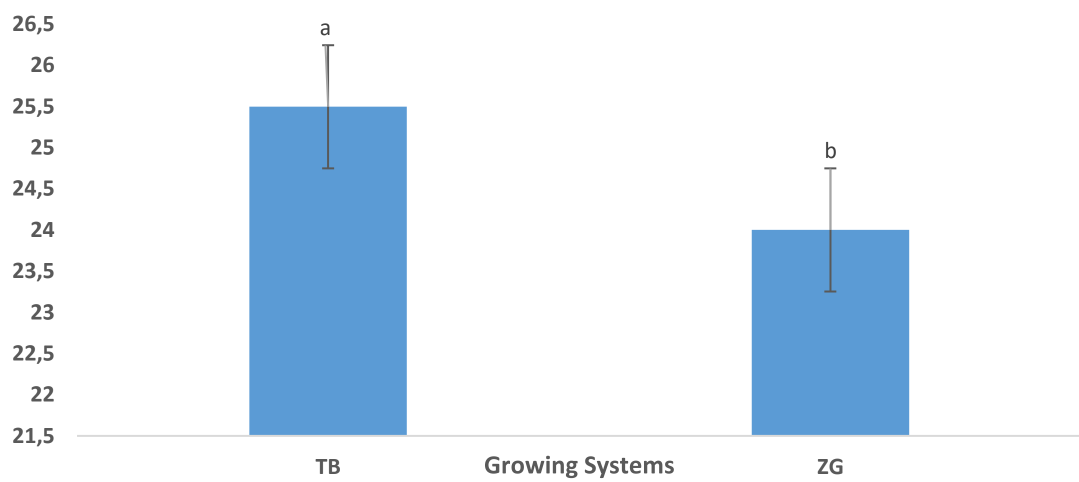

Fig. 3.8. Effect of two hydroponic growing systems i.e. test bed (TB) and Zipgrow (ZG) towers on average leaf cholorphyll contents of two leafy greens basil (*Ocimum basilicum*) and lettuce (*Lactuca sativa*).

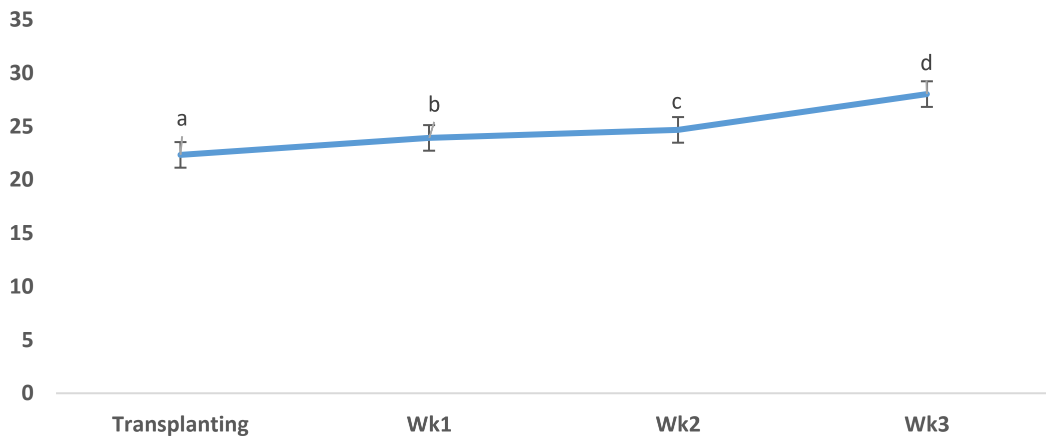

Fig. 3.9. Average leaf cholorphylll contents of of two leafy greens basil (*Ocimum basilicum*) and lettuce (*Lactuca sativa*) grown in two hydroponic growing systems i.e. test bed (TB) and Zipgrow (ZG) towers after one week (Wk1), two weeks (Wk2) and three weeks (Wk3) of tranplanting.

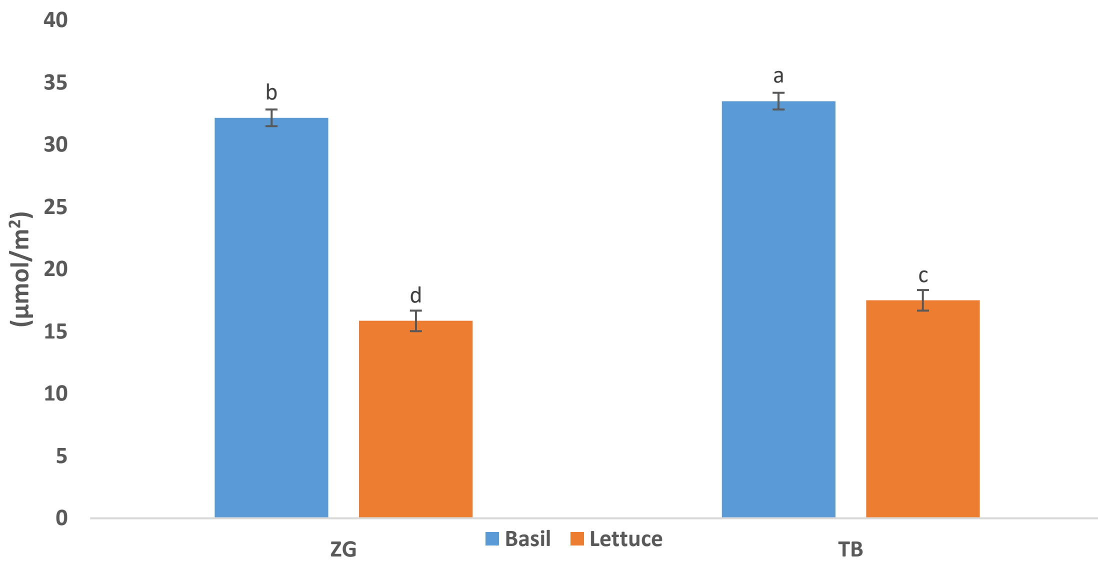

Fig. 3.10. Effect of two hydroponic growing systems i.e. test bed (TB) and Zipgrow (ZG) towers on average leaf cholorphylll contents of two leafy greens basil (*Ocimum basilicum*) and lettuce (*Lactuca sativa*).

3.5. Fresh and Dry Weight

The analysis of variance showed a non-significant interaction between the interaction of growing systems and crops (Table 3.2). The crops grown in TB significantly gained more fresh weight than the crops growin in ZG. Dry weight was not significant effected by cropping systems.

Table. 3.1 Effect of two hydroponic growing systems i.e. test bed (TB) and Zipgrow (ZG) towers on average fresh and dry weight (g) per plant of two leafy greens Basil (*Ocimum basilicum*) and lettuce (*Lactuca sativa*).

	Fresh Weight		Dry Weight	
	ZG	TB	ZG	TB
Basil	28,87	83,28	2,77	4,80
Salad	50,83	115,67	3,68	5,17
	56.08B	83.25A	3.78	4.43

Means not sharing similar letters are significantly different (P≤0.05)

3.6. Energy usage per square meter of cultivation area

SweGreen farm claims to return 94% of every kWh electricity used, back to building in which it is located. The energy consumed by nutrient pump was measured and distributed on the effected growing area 150 m^2. The energy used by LEDs was measured value on the two luminaries (flat system test bed) and distributed on the effected growing area. The energy used by ventilation system was measured and distributed on the effected growing area 600 m^2. The energy consumed by the system and crop plants is as follows:

Table 3.2: Energy used for the plant factory

Energy Consumption	kWh/m^2/day	kJ/m^2/day
The energy consumed by nutrient pump	0.18	648
The energy consumed by LEDs	2.05	7380
The energy consumed by vents	0.2	720
The energy consumed by heating/cooling system	0.45	1620
Total energy consumed m^2/day	**2.89**	**10404**

Total cropping period was 38 days from germination to final harvesting day

3.7. Energy Efficiency

Table 3.3: Calculated energy use per functional unit of produce in test bed system

Basil		**Lettuce**	
Total number of Basil plants per square meter	64	Total number of Lettuce plants per square meter	50
Average fresh weight of one Basil plant	0.050 kg	Average fresh weight of one lettuce plant	0.011 kg
Production of Basil per square meter	0.050 x 64=3.25 kg	Production of Lettuce per square meter	0.011 x 50=5.78 kg
Energy used to produce 1 kg	=10404*38/3.25=121646 kJ/kg	Energy used to produce 1 kg	=10404*38/5.78=68400 kJ/kg

Basil plant in 38 days (912 h)		Lettuce plant in 38 days (912 h)	

3.8. Land Footprint Calculation for lettuce production

Table 3.4: Calculated energy use efficiency for lettuce and basil produced in a plant factory, as compared to open field production systems.

Total Consumed Energy PF per day	10404 kJ/m^2/day
Production of Lettuce per m^2 and crop cycle	5.78 kg
Area needed to produce 1000 kg	173.2 m^2
Energy used to produce 1 kg lettuce	68400 kJ
Energy used to produce 1000 kg lettuce	= 68400*1000 = 68400000 kJ
Yearly production from PV panels in Sweden	72000 kJ/m^2 (Solcellskollen, 2020)
Land area necessary for 68400000 kJ (PV-panels)	= 68400000/72000=950 m^2
Energy used to produce 1 kg lettuce per year in open field	1100 kJ (Barbosa et al., 2015)
Production open field	9.1 t/ha (Jordbruksverket, 2020)
Area needed to produce 1000 kg lettuce in open field	256.4 m^2
Land area (PV-panels) for producing 1000 kg in PF	950 m^2
Energy content lettuce	60 kJ/kg (Livsmedelsverket.se, retrieved on 2020-11-27)
Energy efficiency = energy in product/energy used	= 60/68400=0.0008= 0.08%

The land foot print calculation was done in order to explain the resource use efficiency of the system. The total energy used to provide light, heating and ventiliation to system was calculated as 10404 kJ/m2/day. The lettuce produced per square meter from this system was 5.78 kg and the energy used to produce 5.78 kg of lettuce was estimated as 68400 kJ. In order to calculate the energy efficiency, reference yearly production (72000 kJ/m^2) of electricity from PV panels in Sweden was used from Solcellskollen (2020). The energy used to produce 1 kg lettuce per year in open field (1100 kJ) was taken from the findings of Barbosa et al., (2015). The data for average production of lettuce in open field systems in Sweden was taken from Jordbruksverket (2020), and was estimated as 9.1 t/ha. The land use to produce 1000 kg of lettuce in an open field system was calculated to be 110 m^2, whereas the land (for PV-panels) needed to produce 100 kg of lettuce in the plant factory used in the study was calculated to 950 m^2. The energy efficiency (energy in product/energy for production) calculated for this system was 0.08%.

Chapter 4: Discussion

This study showed that basil and lettuce performed better in terms of plant height in vertical layer test bed (TB) as compared to zip grow (ZG) towers. Weekly measurements of plant height also showed a consistent increasing pattern. Saha et al., (2016) also reported the same results of persistent increase in the height of basil and lettuce plants during extended cropping period (Lennard & Leonard, 2006, Patel et al., 2014). Walters & Currey, (2015) also reported the similar results during their studies on comparing different types of basil cultivars in different types of hydroponic growing systems where the height of different basil cultivars ranged from 9-25cm. Pantanella et al., (2012) also reported parallel results during their studies on lettuce growth in hydroponics. The lettuce plant height ranged from 13-19 cm in a study done by Maboko & Plooy, (2009) where they studied the effect of plant spacing on production of lettuce in hydroponic soil less system. Touliatos et al., (2016) reported that hydroponic vertical farming can enable more lettuce production per unit area as compared to conventional horizontal hydroponic. It was also observed that plant height was more uniform in ZG as compared to TB. The plant plugs started to collapse on one side due to more height of plants in case of Basil in TB. This kind of scenario was not observed in case of ZG systems because of the presence of substrate and compact tower inner sides which holds the plug firmly. A more stable system to hold the plugs in TB system is needed to prevent the lodging of plants during longer cropping periods.

Number of leaves, length and width indicates the yield in leafy greens (Al-Tawaha et al., 2018). During the present study, it was found that the number of leaves of both crops grown in vertical layer test bed was significantly higher than that of ZG system. Al-Tawaha et al., (2018) reported in his studies on quality and quantity of lettuce leaves in hydroponics that minimum and maximum number of lettuce leaves can be from 20 to 45 depending upon the lettuce cultivar and cropping period. Raimondi et al., (2006) concluded in his findings that higher plant density in hydroponics system can lead to higher plant height and leaf numbers in basil and lettuce. Maboko & Plooy, (2009) reported in their study that plant density and spacing directly effects the leaf numbers and index

Key information about transpiration and stress can be provided by leaf temperature (Chiachung, 2015). The detection of leaf temperature by using IR thermometer is a useful non-contact measurement. Ideally, leaf temperature should be somewhat lower (1-2°C) than the air temperature because of the transpiration process acting as coolant system for plants (Tang et al., 2017). Leaf air temperature is also directly proportional to relative humidity (RH). An increase or decrease in RH can lead to increase or decrease of leaf temperature. It was also found that the leaf temperature of crops grown in TB was lower than that of crops grown in ZG. An increased leaf temperature than the surrounding air temperature can be indicating that crop is in some kind of stress (Tang et al., 2017). This study showed that vertical layer TB growing systems helps to maintain a lower leaf temperature resulting in low crop stress.

The plant health and quality can be depicted by the cholorphyll contents of leaf (Ristic et al., 2007, Saha et al., 2016) which on the other hand is dependent on the availability of light. It is a well-known fact that without light, plants cannot perform photosynthesis which is the key to perform various metabolic processes inside plant body. During this experiment, LED lights were used 18 hours per day to provide light for the plants. The leaf chlorophyll contents of crops grown in TB system were found to be higher than the crops grown in ZG system. This indicates a higher photosynthetic capacity in crops grown in TB. Saha et al., (2016) reported an increase in leaf chlorophyll contents of crops grown in vertical layer hydroponic system. Solis-Toapanta & Gómez, (2019) reported in their studies that the leaf chlorophyll contents were also found to increase along with the cropping period. These results are supported by the findings of Nobel et al., (1975) that young plants with small sized leaves have less chlorophyll to perform photosynthesis as compared to the mature plants with big leaves. Pennisi et al., (2019) also reported increase in leaf chlorophyll contents and photosynthetic activity of lettuce under LED lights resulting in higher yields. Bergstrand et al., (2016) also reported similar results while investigating the acclimatization of greenhouse crops to different light intensities.

Fresh weight is an important indicator to monitor the growth of plant and its yield especially in case of leafy vegetables which are mostly comprised of water. The higher fresh weight in the TB system can be due to more plant biomass which could be the result of more photosynthetic activity in the plants grown in TB. Touliatos et al., (2016) reported that fresh weight and yield of lettuce can be increased in vertical farming hydroponic system Savidov (2005) reported the same findings of increased fresh and dry weight in hydroponically grown vegetables (Lennard and Leonard, 2006). Raimondi et al., (2006) also found similar results of increased biomass production of hydroponically produced different cultivars of Basil (Zheljazkov et al., 2008, Bulgari et al., 2016).

Indoor farming uses more electricity and energy than green houses and conventional farming for food production because of provision of artificial light and ventilation systems (Eaves and Eaves 2018). However, the energy efficiency of indoor plant factories exceeds the energy efficiency of most efficient greenhouses especially in colder climates (Graamans et al., 2017, Zhang & Kacira, 2020). (Molin & Martin, 2018) reported in their earlier studies that the energy consumption for the functional unit to produce one basil plant was calculated to be 4900 kJ. Orsini et al., (2020) calculated the energy use efficiency of lettuce grown in plant factories with artificial lighting as 3600-504000 kJ/g, which is within the same range as in this study, however, higher as compared to open-field systems. It was also found out during the same study the energy efficiency depends upon the lighting, climate control and production facilities with a claim that energy use efficiency of lettuce grown in plant factories is 20 times lower than the conventional lettuce cultivation. The indoor production of fresh produce can be a promising way to not only supply urban population with fresh food but also to address the problems of sustainable use of natural resources and climate change in the long run. The increase in land use efficiency is requiredin the predicted scenario of predicted urbanization and increase in population (Lambin and Meyfroidt, 2011). The adoption of vertical farming with soilless cultivation system is shown to increase the yield as compared to conventional open field cultivation systems. Barbosa et al. (2015) reported 10-12 times increase in land surface use efficiency of lettuce grown in hydroponics as compared to conventional production systems. In another study by Kozai et al., (2019), the number of plant per unit area and increased yield in plant factories can give land surface use efficiency up to 3300 and 1500 g m^{-2} d^{-1} in lettuce and basil respectively (Pennisi et al., 2019).

The production of leafy greens and other short duration vegetables in indoor vertical farming systems seems like to lessen down the threats from conventional food production system to environment and climate change and increase the resource use efficiency, but it needs an inclusive integration of smart technologies to lower down the energy usage for mimicking the natural environment inside vertical farms.

5. Conclusions

Overall, production of basil and lettuce in test bed vertical layer system has shown better plant growth and yield as compared to zip grow system. The energy use efficiency and land use efficiency was also found better in vertical layer production system as compared to conventional production. There is a need of more robust research taking in account light intensity/spectrum, CO_2 levels and nutritional inputs. A special focus shall be given for the quantification of resource use efficiency and environmental factors on a commercial level by taking in account a wide range of crops other than leafy greens. The land use efficiency was estimated to be almost 5 times higher for the plant factory if driven by PV-panels, as compared to open field production of lettuce.

References

Al-Chalabi, M. (2015). Vertical farming: Skyscraper sustainability? Sustainable Cities and Society, 18, 74–77. https://doi.org/10.1016/j.scs.2015.06.003

Alsanius, B.W., von Essen, E., Hartmann, R., Vågsholm, I., Doyle, O., Schmutz, U., Stützel, H., Fricke, A. and Dorais, M. (2019). The "one health"-concept and organic production of vegetables and fruits. Acta Hortic. 1242, 1-14. DOI: 10.17660/ActaHortic.2019.1242.1. https://doi.org/10.17660/ActaHortic.2019.1242.1

Al-Tawaha, A., Al-Karaki, G., Al Tawaha, A. R., Sirajuddin, S., Makhadmeh, I., Edaroyati, P., Wahab, M., Youssef, R., Sultan, W., & Massadeh, A. (2018). Effect of water flow rate on quantity and quality of lettuce (Lactuca sativa L.) in nutrient film technique (NFT) under hydroponics conditions. Bulgarian Journal of Agricultural Science, 24, 791–798.

Avgoustaki, D. D., & Xydis, G. (2020). Plant factories in the water-food-energy Nexus era: A systematic bibliographical review. *Food Security*, *12*(2), 253–268. https://doi.org/10.1007/s12571-019-01003-z

Barbosa, G., Gadelha, F., Kublik, N., Proctor, A., Reichelm, L., Weissinger, E., Wohlleb, G., & Halden, R. (2015). Comparison of Land, Water, and Energy Requirements of Lettuce Grown Using Hydroponic vs. Conventional Agricultural Methods. *International Journal of Environmental Research and Public Health*, *12*, 6879–6891. https://doi.org/10.3390/ijerph120606879

Benke, K., & Tomkins, B. (2017). Future food-production systems: Vertical farming and controlled-environment agriculture. Sustainability: Science, Practice and Policy, 13(1), 13–26. https://doi.org/10.1080/15487733.2017.1394054

Bergstrand, K.-J., Mortensen, L. M., Suthaparan, A., & Gislerød, H. R. (2016). Acclimatisation of greenhouse crops to differing light quality. Scientia Horticulturae, 204, 1–7. https://doi.org/10.1016/j.scienta.2016.03.035

Besthorn, F. H. (2013). Vertical Farming: Social Work and Sustainable Urban Agriculture in an Age of Global Food Crises. Australian Social Work, 66(2), 187–203. https://doi.org/10.1080/0312407X.2012.716448

Bulgari, R., Baldi, A., Ferrante, A., & Lenzi, A. (2016). Yield and quality of basil, Swiss chard and rocket microgreens grown in a hydroponic system. New Zealand Journal of Crop and Horticultural Science, 45. https://doi.org/10.1080/01140671.2016.1259642

Carey, R., K. Larsen, and J. Sheridan. (2016). Melbourne's Food Future: Planning a Resilient City Foodbowl: A Summary Briefing from the Food-print Melbourne Project. Melbourne: Victorian Eco-Innovation Lab, The University of Melbourne.

Chiachung, C. (2015). Determining the Leaf Emissivity of Three Crops by Infrared Thermometry. 15, 11387-11401. https://doi:10.3390/s150511387.

Colstee, V. (2020). The history of indoor vertical farming. (n.d.). Retrieved October 16, 2020, from https://www.eitfood.eu/blog/post/the-origins-of-indoor-vertical-farming

Crumpacker, M. (2018). A Look at the History of Vertical Farming. Medium. https://medium.com/@MarkCrumpacker/a-look-at-the-history-of-vertical-farming-f4338df5d0f4

Despommier, D. (2011). The vertical farm: Controlled environment agriculture carried out in tall buildings would create greater food safety and security for large urban populations. *Journal Für*

Verbraucherschutz Und Lebensmittelsicherheit, *6*, 233–236. https://doi.org/10.1007/s00003-010-0654-3

Eaves, J., & Eaves, S. (2018). Comparing the Profitability of a Greenhouse to a Vertical Farm in Quebec. Canadian Journal of Agricultural Economics/Revue Canadienne d'agroeconomie, 66(1), 43–54. https://doi.org/10.1111/cjag.12161

European Commission. 2005. Commission recommendation of 1 March 2005 concerning a coordinated programme for the official control of foodstuffs for 2005 (2005/175/EC). Off. J. Eur. Union L 59: 27–39.

European Food Safety Authority Panel on Biological Hazards. 2013.Scientific opinion on the risk posed by pathogens in food of non-animal origin. Part 1.EFSA J. 11:138.

Frezza, D., León, A., Logegaray, V., Chiesa, A., Desimone, M., & Diaz, L. (2005). SOILLESS CULTURE TECHNOLOGY FOR HIGH QUALITY LETTUCE. Acta Horticulturae, 697, 43–48. https://doi.org/10.17660/ActaHortic.2005.697.3

Graamans, L., Van den Dobbelsteen, A., Meinen, E., and Stanghellini, C. (2017). Plant factories; crop transpiration and energy balance. Agric. Syst. 153, 138–147. https://doi.org/10.1016/j.agsy.2017.01.003.

Gullino, M. L., Gilardi, G., & Garibaldi, A. (2019). Ready-to-Eat Salad Crops: A Plant Pathogen's Heaven. Plant Disease, 103(9), 2153–2170. https://doi.org/10.1094/PDIS-03-19-0472-FE

Hancock, D., T. Besser, J. Lejeune, M. Davis, and D. Rice. 2001. Thecontrol of VTEC in the animal reservoir.Int. J. Food Microbiol.66:71–78.

Jay, M. T., M. Cooley, D. Carychao, G. W. Wiscomb, R. A. Sweitzer,L. Crawford-Miksza, J. A. Farrar, D. K. Lau, J. O'Connell, A.Millington, R. V. Asmundson, E. R. Atwill, and R. E. Mandrell.2007.Escherichia coliO157:H7 in feral swine near spinach fields and cattle, central California coast. Emerg. Infect. Dis. 13:1908–1911.27.

Jordbruksverket. (2020). *Skörd av trädgårdsväxter 2019. Horticultural production 2019.* https://jordbruksverket.se/om-jordbruksverket/jordbruksverkets-officiella-statistik

Jenkins, D. (2017). Rise to the challenge: Vertical farming within the urban environment. https://unitec.researchbank.ac.nz/handle/10652/4329

Kalantari, F., Tahir, O. M., Joni, R. A., & Fatemi, E. (2018). Opportunities and Challenges in Sustainability of Vertical Farming: A Review. Journal of Landscape Ecology, 11(1), 35–60. https://doi.org/10.1515/jlecol-2017-0016

Kozai, T., Niu, G., & Takagaki, M. (2019). *Plant Factory: An Indoor Vertical Farming System for Efficient Quality Food Production*. Academic Press.

Lages Barbosa, G., Almeida Gadelha, F. D., Kublik, N., Proctor, A., Reichelm, L., Weissinger, E., Wohlleb, G. M., & Halden, R. U. (2015). Comparison of Land, Water, and Energy Requirements of Lettuce Grown Using Hydroponic vs. Conventional Agricultural Methods. *International Journal of Environmental Research and Public Health*, *12*(6), 6879–6891. https://doi.org/10.3390/ijerph120606879

Laidler, M. R., M. Tourdjman, G. L. Buser, T. Hostetler, K. K. Repp,R. Leman, M. Samadpour, and W. E. Keene. (2013). Escherichia coliO157:H7 infections associated with consumption of locally grownstrawberries contaminated by deer.Clin. Infect. Dis. 57:1129–1134.

Langelaan, H. C., & Silva, F. P. D. (2013). Technology options for feeding 10 billion people. Food Engineering, 1(1), 1–16. https://data.europa.eu/doi/10.2861/33619

Lemmers, N. (2016). Eten in de steentijd. https://www.hunebednieuwscafe.nl/2016/09/eten-in-de-steentijd/
Lennard, W. A., & Leonard, B. V. (2006). A Comparison of Three Different Hydroponic Sub-systems (gravel bed, floating and nutrient film technique) in an Aquaponic Test System. Aquaculture International, 14(6), 539–550. https://doi.org/10.1007/s10499-006-9053-2
Lennard, W.A., Leonard, B.V. (2006). A Comparison of Three Different Hydroponic Sub-systems (gravel bed, floating and nutrient film technique) in an Aquaponic Test System. Aquacult Int. 14, 539–550. https://doi.org/10.1007/s10499-006-9053-2
Maboko, M. M., & Plooy, C. P. D. (2009). Effect of plant spacing on growth and yield of lettuce (Lactuca sativa L.) in a soilless production system. South African Journal of Plant and Soil, 26(3), 195–198. https://doi.org/10.1080/02571862.2009.10639954
Manzocco, L., Foschia, M., Tomasi, N., Maifreni, M., Costa, L. D., Marino, M., Cortella, G., & Cesco, S. (2011). Influence of hydroponic and soil cultivation on quality and shelf life of ready-to-eat lamb's lettuce (Valerianella locusta L. Laterr). Journal of the Science of Food and Agriculture, 91(8), 1373–1380. https://doi.org/10.1002/jsfa.4313
McGee, H. (2004). McGee On Food & Cooking: An Encyclopedia of Kitchen Science, History and Culture. Hodder & Stoughton; Revised and Updated edition (8 Nov. 2004). p 252.
Molin, E., & Martin, M. (2018). Assessing the energy and environmental performance of vertical hydroponic farming. IVL Swedish Environmental Research Institute. https://www.ivl.se/download/18.2aa2697816097278807e72e/1522250395541/C299.pdf
Savidov, N. (2005). Evaluation of aquaponics technology in Alberta, Canada Aquaponics J., 37, pp. 20-25.
Nagle, L. K. (2016). Vertical Food Production: Applications and Modeling. https://etda.libraries.psu.edu/catalog/29498
Nobel, P.S., Zaragoza, L.J. & Smith, W.K. 1975 Relation between mesophyll surface area, photosynthetic rate, and illumination level during development for leaves of Plectranthus parviflorus Henckel Plant Physiol.55 1067 1070.
Pantanella, E., Cardarelli, M., Colla, G., Rea, E. and Marcucci, A. (2012). Aquaponics vs. hydroponics: production and quality of lettuce crop. Acta Hortic. 927, 887-893 DOI: 10.17660/ActaHortic.2012.927.109. https://doi.org/10.17660/ActaHortic.2012.927.109.
Patel, J. S., Zhang, S., & Novaes, M. I. C. de. (2014). Effect of Plant Age and Acibenzolar-S-methyl on Development of Downy Mildew of Basil. HortScience, 49(11), 1392–1396. https://doi.org/10.21273/HORTSCI.49.11.1392
Quinn, H. (2017). Urbanizing Agriculture; Vertical Farming as a Potential Solution to Food Security Issues. https://repository.arizona.edu/handle/10150/626194
Ragaert, P., F. Devlieghere, and J. Debevere. 2007. Role of microbiological and physiological spoilage mechanisms during storage of minimally processed vegetables. Postharvest Biol. Technol. 44: 185–194.
Ramin Shamshiri, R., Kalantari, F., C. Ting, K., R. Thorp, K., A. Hameed, I., Weltzien, C., Ahmad, D., Mojgan Shad, Z., 1. (2018). Advances in greenhouse automation and controlled environment agriculture: A transition to plant factories and urban agriculture. International Journal of Agricultural and Biological Engineering, 11(1), 1–22. https://doi.org/10.25165/j.ijabe.20181101.3210

Saha, S., Monroe, A., & Day, M. R. (2016). Growth, yield, plant quality and nutrition of basil (Ocimum basilicum L.) under soilless agricultural systems. Annals of Agricultural Sciences, 61(2), 181–186. https://doi.org/10.1016/j.aoas.2016.10.001

Shamshiri, R, R., Kalantari, F., Ting, K. C., Thorp, K. R., Hameed, I. A., Weltzien, C., Ahmad, D., & Shad, Z. M. (2018). Advances in greenhouse automation and controlled environment agriculture: A transition to plant factories and urban agriculture. 1-22. https://doi.org/10.25165/j.ijabe.20181101.3210

Snir, A., Nadel, D., Groman-Yaroslavski, I., Melamed, Y., Sternberg, M., Bar-Yosef, O., Weiss, E. (2015). The Origin of Cultivation and Proto-Weeds, Long Before Neolithic Farming. Public Library of Science (PLoS One 10) no. 7.

Söderlund, R., I. Hedenström, A. Nilsson, E. Eriksson, and A. Aspan (2012). Genetically similar strains of Escherichia coli O157:H7 isolated from sheep, cattle and human patients. BMC Vet. Res. 8:200.

Söderqvist, K. et al. (2019). Season and Species: Two Possible Hurdles for Reducing the Food Safety Risk of Escherichia coli O157 Contamination of Leafy Vegetables Journal of Food Protection, 82 (2), ss.247-255. DOI:10.4315/0362-028X.JFP-18-292

Solcellskollen. (2020). Yearly production from PV panels. https://solcellskollen.se/ Retrieved on 2020-11-25

Solis-Toapanta, E., & Gómez, C. (2019). Growth and Photosynthetic Capacity of Basil Grown for Indoor Gardening under Constant or Increasing Daily Light Integrals. HortTechnology, 29(6), 880–888. https://doi.org/10.21273/HORTTECH04442-19

Swirski, A. L., D. L. Pearl, M. L. Williams, H. J. Homan, G. M. Linz,N. Cernicchiaro, and J. T. LeJeune. 2014. Spatial epidemiology ofEscherichia coliO157:H7 in dairy cattle in relation to night roosts of Sturnus vulgaris (European starling) in Ohio, USA (2007–2009).Zoonoses Public Health61:427–435.

Tang, K., Struik, P., Amaducci, S., Stomph, T. J., & Yin, X. (2017). Hemp (Cannabis sativa L.) leaf photosynthesis in relation to nitrogen content and temperature: Implications for hemp as a bio-economically sustainable crop. GCB Bioenergy. https://doi.org/10.1111/gcbb.12451

Team, Z. (2020). What is a ZipGrowTM Tower? ZipGrow. https://zipgrow.com/what-is-a-zipgrow-tower/

Tomasi, N., Pinton, R., Dalla Costa, L., Cortella, G., Terzano, R., Mimmo, T., Scampicchio, M., & Cesco, S. (2015). New 'solutions' for floating cultivation system of ready-to-eat salad: A review. Trends in Food Science & Technology, 46(2, Part B), 267–276. https://doi.org/10.1016/j.tifs.2015.08.004

Touliatos, D., Dodd, I., & Mcainsh, M. (2016). Vertical farming increases lettuce yield per unit area compared to conventional horizontal hydroponics. Food and Energy Security, 5. https://doi.org/10.1002/fes3.83

Wahlström, H., E. Tysen, E. O. Engvall, B. Brandström, E. Eriksson,T. Mörner, and I. Vågsholm. 2003. Survey of *Campylobacter* species, VTEC O157 and *Salmonella* species in Swedish wildlife. Vet. Rec.153:74–80.

Walters, K., & Currey, C. (2015). Hydroponic Greenhouse Basil Production: Comparing Systems and Cultivars. Hort Technology, 25, 645–650. https://doi.org/10.21273/HORTTECH.25.5.645

World Health Organization, Food and Agriculture Organization of the United Nations (WHO/FAO). 2008. Microbiological hazards in fresh leafy vegetables and herbs: meeting report. Microbiological Risk Assessment Series No. 14. WHO/FAO, Geneva.

Zhang, Y., and M. Kacira. 2020. Comparison of energy use efficiency of greenhouse and indoor plant factory system. Eur. J. Hortic. Sci. 85(5), 310–320 | ISSN 1611-4426 print, 1611-4434 online | https://doi.org/10.17660/eJHS.2020

Zheljazkov, V. D., Callahan, A., & Cantrell, C. L. (2008). Yield and oil composition of 38 basil (*Ocimum basilicum* L.) accessions grown in Mississippi. Journal of Agricultural and Food Chemistry, 56(1), 241–245. https://doi.org/10.1021/jf072447yLambin, E.F., and Meyfroidt, P. (2011). Global land use change, economic globalization, and the looming land scarcity. Proc. Natl. Acad. Sci. USA 108, 3465–3472. https://doi.org/10.1073/pnas.1100480108

Kozai, T., Amagai, Y., and Hayashi, E. (2019). Towards sustainable plant factories with artificial light (PFALs): from green houses to vertical farms (Ch. 6). In Achieving Sustainable Greenhouse Cultivation, L. Marcelis, and E. Heuvelink, eds. (Cambridge, UK: Burleigh Dodds Science Publishing), p. 177–204. http://dx.doi.org/10.19103/AS.2019.0052.06.

Pennisi, G., Blasioli, S., Cellini, A., Maia, L., Crepaldi, A., Braschi, I., Spinelli, F., Nicola, S., Fernandez, J.A., Stanghellini, C., Marcelis, L.F.M., and Orsini, F. (2019). Unravelling the role of red:blue LED lights on resource use efficiency and nutritional properties of indoor grown sweet basil. Front. Plant. Sci. 10, 305. https://doi.org/10.3389/fpls.2019.00305.

Appendix

Nutrient solution for **Swegreen**

Polyfeed Solo 2020

Version 1.12 LMI AB

Page: 1

Printout 2020-07-07 16:15

C:\Users\Monika.LMISRV\LMI AB\Försäljning - Dokument\Program\SluFert_LMI\Plantagon.mdb

Code: **Polyfeed 2020**

Raw water	Share
1: KONDENSVATTEN	96
2:	
3: KRANVATTEN 1808	4
Sum:	100

Aimed solution: KRYDDOR

Water temperature 20 °C

CO_2 in the air: 400 ppm

Stock solution tanks

Tap water: KONDENSVATTEN

Injection: 1,5 %

Tank	Size (litre)	Proportional injection
1	25	50
2	25	50
3	10	10
4		
5		
Sum:		110

	Outgoing solution		Relative to N
pH	6,7		
EC	2,02	mS/cm	
NO3-N	172	mg/l	83
NH4-N	36	mg/l	17
N	208	mg/l	100
P	39	mg/l	19
K	243	mg/l	117
Mg	21,7	mg/l	10,4
S	37,2	mg/l	17,8
Ca	131	mg/l	63
Na	1	mg/l	0
Cl	1	mg/l	1
Mn	0,92	mg/l	0,44
B	0,20	mg/l	0,10
Cu	0,24	mg/l	0,12
Fe	2,55	mg/l	1,22
Zn	1,05	mg/l	0,50
Mo	0,024	mg/l	0,012
HCO3	48	mg/l	

Fertilizer

Name	Tank	Amount		Alternative name
Polyfeed Solo	1	1,700	kg	NPK 14-4-21
kaliumnitrat	1	0,750	kg	Krista-K, Multi-K,kalisalpeter
magnesiumsulfat	1	0,300	kg	Krista-MgS, Bittersalt
magnesiumnitrat	1	0,300	kg	Krista-Mag, Magnisal
monokaliumfosfat	1	0,300	kg	Krista-MKP, Multi-MKP, PeaK
kalciumnitrat	2	2,500	kg	kalksalpeter
mangankelat 6,1%	2	0,025	l	mangankelat 81g/l
Bor Flytande	2	0,000	l	
Järnkelat 3 %	2	0,150	l	DTPA
kopparnitrat	2	0,002	l	
zinknitrat	2	0,009	l	
natriummolybdat	2	0,000	kg	
kaliumkarbonat	3	0,600	kg	pottaska

Nytt grundrecept med MKP istället för MAP. Proportioner av råvatten korrigerat.