SiEUGreen
Sino-European innovative green and smart cities

Sino-European Innovative Green and Smart Cities

Deliverable 2.2

Evaluation of crop techniques

Lead Partner: NIBIO

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SiEUGreen

The project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement N 774233, and from the Chinese Ministry of Science and Technology.

Throughout SiEUGreen's implementation, the EU and China will share technologies and experiences, thus contributing to the future development of urban agriculture and urban resilience in both.

The project SiEUGreen aspires to enhance EU-China cooperation in promoting urban agriculture for food security, resource efficiency and smart, resilient cities.

The project contributes to the preparation, deployment and evaluation of showcases in five selected European and Chinese urban and peri-urban areas: a previous hospital site in Norway, community gardens in Denmark, previously unused municipal areas with dense refugee populations in Turkey, big urban community farms in Beijing and new green urban development in Changsha in Central China.

A sustainable business model allowing SiEUGreen to live beyond the project period is planned by joining forces of private investors, governmental policy makers, communities of citizens, academia and technology providers.

Technical references

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[1] **PU** = Public
PP = Restricted to other programme participants (including the Commission Services)
RE = Restricted to a group specified by the consortium (including the Commission Services)
CO = Confidential, only for members of the consortium (including the Commission Services)

Document history			
Version	**Date**	**Author - Partner**	**Summary of changes**
1.0	08/05/2019	NIBIO	Initial Draft
1.1	21/05/2019	NIBIO	Draft circulated to NIBIO and NMBU
1.2	25/06/2019	NIBIO	Final draft submitted to project coordinator
2.0	30/06/2019	NIBIO	Final version submitted
3.0	24/10/2019	NIBIO	Revised version submitted after the request for revision comments from the commission on 14/10/2019

Executive summary

The SiEUGreen project aims to enhance the EU-China cooperation in promoting urban agriculture for food security, resource efficiency and smart, resilient cities. Plant cultivation technology is one of the main components of urban farming. This report presents WP2, D2.2-*Evaluation of crop techniques*.

During the first 18-month project period, we have evaluated four main crop-cultivating techniques; (1) paper based balcony garden (microgreen technique), (2) hydroponics, (3) aquaponics and (4) soil (compost or peat) based systems. Detailed descriptions of the completed experiments, the validated protocols and recommendations for the implementation of these technologies in SiEuGreen showcases are provided in this report. With each crop cultivation system, we have tested key factors (e.g. LED light, deep learning for rapid evaluation of biomass, compost compared with peat) affecting plant growth and yield (biomass).

In order to develop a protocol for the **paper-based balcony garden** (i.e. microgreen technique) which shall be implemented in showcases including Fredrikstad in Norway, we tested more than 10 vegetable cultivars/seeds in the completed experiments. Our data suggest that the paper based microgreen technique is easy and can be adopted in showcases where this technique is desirable. The validated protocol and key recommendations are (1) to keep constant moisture and (2) to water the germinated seeds 2-3 times a day to achieve optimal conditions for a paper-based balcony garden and produce fresh and healthy microgreens.

For the second crop cultivation technique, **hydroponics (soilless plant cultivation system),** we have selected two vegetable cultivars, lettuce and cucumber, with the focus on rapid biomass evaluation using a deep learning technique and investigation of the effect of various light spectra on vegetable growth. Results showed that 'Crispy' lettuce was grown healthily in a simple nutrient film technique (NFT) setup; its fresh biomass could be very well predicted using the UNET deep learning method through automatic segmentation, which permits the vegetable yield to be easily evaluated and the hydroponic plant growth system to be utilized in Fredrikstad and other showcases in the future. Red light was more effective in stimulating lettuce growth compared with plants treated by white light, despite plants having lower chlorophyll content when subjected to red light. For cucumber production, we have tested a floating hydroponic crop production system. Our data indicate that the floating system promoted significant vegetative growth whereas the yield of cucumber was similar to that of cucumber plants grown in a rock wool system. For the future implementation of the hydroponic crop production system in the showcases like Fredrikstad, the floating system is preferable for cucumber production.

The third tested crop cultivation technique was **aquaponics**, meaning combined fish and vegetable production. We focused on the green crop production and chose lettuce as our vegetable crop. The experimental data showed that lettuce acquired sufficient nutrients, which was produced by the fish fingerlings from Setesdalen, Norway, and biomass of lettuce was comparable with that produced in hydroponics. However, lettuce plants grown in hydroponics were generally higher in photosynthetic activities and final yield compared with aquaponics, which was probably due to a more optimal nutrient supply. This comparison of hydroponics and aquaponics provides valuable data for the implementation of these plant growth systems in the showcases in the SiEUGreen project, in particular the Fredrikstad showcase.

The fourth important crop production system is **the recycled compost-based system**, important for circular economy. The "Den Lille Gartner" Maxi system with a water/nutrient reservoir has been tested and showed that it is very suitable for cultivating small vegetables

like herbs and greens in the kitchen. Using this system we have also concluded that compost made from a mixture of waste from the garden and food (vermicompost) is as suitable for herbs and greens as peat based compost. For tomato production on balconies, compost was able to produce a similar yield and higher quality tomatoes with less cracking fruits, compared with peat in a hot summer. Roof top gardens with blackberries grown in the best compost (85:15 household:vermicompost) had twice the amount of Vitamin C, compared with ones in peat. Our preliminary conclusion for all crops tested is that compost gives equal yields, and improved plant quality compared to peat. Urine-based recycling fertilizer, Aurin, with lower NO_3/NH_4 ratio, promoted biomass accumulation of maize plants grown in soil. The biomass and height of Chinese cabbage increased with the increase in kitchen compost added in coconut shaft from zero to 60 kg/m^{-3} while the ones with the best quality, the highest vitamin C and sugar, were produced in coconut shaft with 45 kg/m^{-3} kitchen compost.

Taken together, this technical report documents the evaluation of four different plant growing techniques providing protocols, recommendations and guidelines for future implementation of each crop production technique in different showcases within the framework of the SiEUGreen project.

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1. Introduction

Due to the conflict between population increase and loss of arable land, sustainable food production that is water, space and energy efficient is in urgent demand. Development of green technologies in the SiEUGreen project aims to utilize limited resources in cities to provide citizens with sufficient fresh fruits and vegetables. It mainly includes paper-based, hydroponics and aquaponics systems for plant production. The hydroponic cultivation system is becoming popular in China and Europe as it possesses a unique advantage by reducing/eliminating soil-borne pathogens in food crop production to protect the yield and reduce the application of pesticide chemicals. The innovations regarding the green technology lie in generating growth systems based on local resources (water, soil and nutrients) in the city rather than importing from the outside, and enabling the population to grow their own food near their homes.

Four major crop techniques, including paper based, hydroponics and aquaponics systems and soil based methods were evaluated during the first year of the SiEUGreen project. Based on the concept of a green and circular economy, we designed experiments specifically to optimize these techniques in urban agriculture:

1) Microgreens grown in paper towels and/or printer paper;
2) Hydroponic experiment with NFT in Ås: Searching for the relationship between head projected area and head fresh biomass of 'Crispy' lettuce in NFT;
3) Hydroponics vs. aquaponics in Landvik: Comparison of lettuce growth and production;
4) Hydroponic experiment with a floating system in Særheim: a) comparing physiological condition and yield of 'Crispy' lettuce under red and white light conditions; b) cucumber, comparing physiological condition and yield of cucumber growing in water and rock wool growth media;
5) Soil based methods with composts as fertilizer
    a. Comparison between composts and peat in tomato and blackberry growth,
    b. Urine based fertilizer in maize plant cultivation,
    c. Chinese cabbage growth in coconut shaft with added kitchen compost.

The crop techniques evaluated are all conventionally available for greenhouse production in different degrees, which can be implemented in different showcases in Europe and China. This document shows the applicability of these technologies on a small scale, the greenhouse or growth chamber, in preparation for future large scale implementation in different showcases.

Chapter 2 of this deliverable provides a brief overview of crop techniques within the scope of the SiEUGreen project. The chapter also describes the readiness level of the technologies selected for implementation.

Chapter 3 presents the fact sheets on these detailed crop techniques associated with the aim to use the resources provided in a circular system from blue technology.

2. Showcase technologies for cultivating edible plants in urban areas

2.1 Overview of technologies for showcase deployment

The technologies under SiEUGreen that will focus on the reuse of various resources including land, water, waste nutrients, solar energy and biogas have already been established in the SiEUGreen grant agreement (GA). The concept demonstrates a strong focus on agricultural food production with zero or minimum transport, solar energy utilization, water saving and wastewater reuse, waste recycling, residents' involvement and organic green UA for smart city residents. The crop techniques evaluated currently are using prepared nutrient solutions (Figure 1); however, future trials will involve nutrients derived from biogas digestate based on blackwater and other organic household wastes, provided that no problematic consequences arise for plants or humans.

Four main crop technologies are evaluated in Task 2.1: 1) paper based microgreen growing technology adopted from China; 2) hydroponics and aquaponics; 3) soil-based traditional plant growing techniques with organic fertilizers produced from composts of household food waste, which in D2.1 focuses on compost selection, substituting peat in a more environmentally-friendly way.

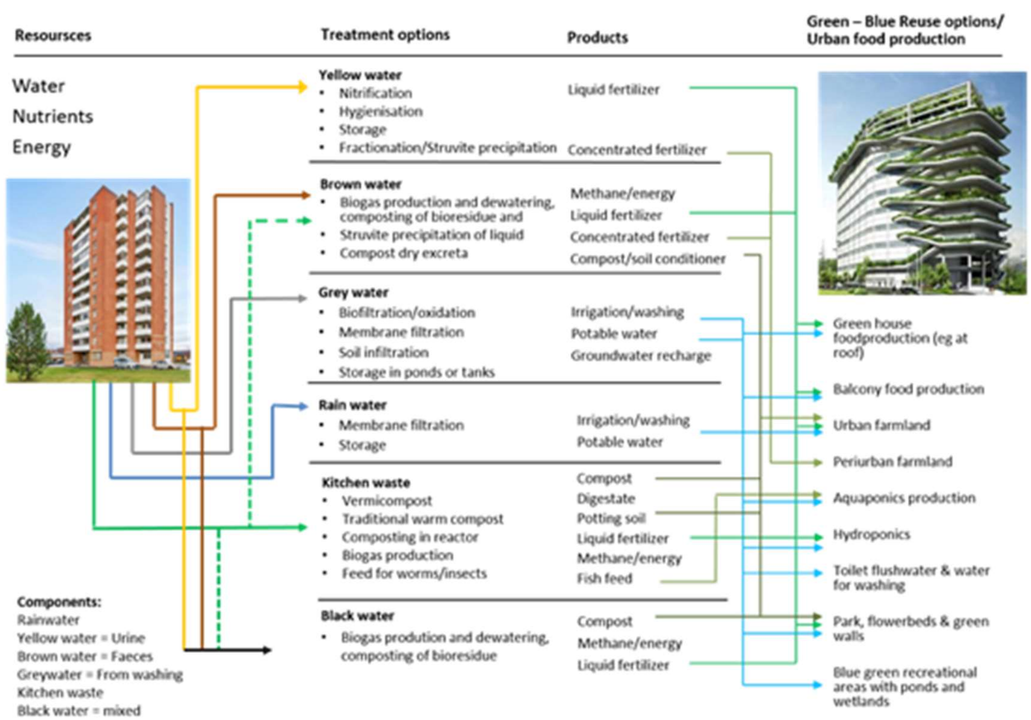


Fig. 1: SiEUGreen models of recyclable resources

2.2 Technology readiness level (TRL)

The TRL levels of the SiEUGreen technologies are established in the GA. The TRL level of the technologies ranges from 3-9. Once the technology is deployed in the showcase it will pass three distinct phases: i) testing of technology in other greenhouses and showcases in Hatay,

ii) data analysis on the evaluation of the implementation, and iii) feedback and optimization of protocols to improve the TRL level and SiEUGreen crop techniques' fact sheets accordingly.

3. SiEUGreen green technology fact sheets

3.1 Paper based microgreen production

Growth system	Paper based microgreen production
Resources	Paper, seeds, water
Expected products	Healthy microgreens with different flavours
Green-blue reuse options	Roots of microgreens can be used for the poultry industry

Short description of technology

Microgreens are young leafy greens with appealing colours, textures and tastes. They include broad bean, black soybean, daikon/Japanese radish, buckwheat, Chinese mahogany, mung bean, sunflower, grass pea, snow pea, mustard, cabbage, radish, buckwheat, lettuce, spinach etc. They have been more and more popular in recent years due to their attractive colour, rich flavour and highly valued bioactive compounds improving human health conditions, including antioxidants, vitamins and minerals. They can be consumed as either a main dish or supplementary ingredients providing extra aroma for main dishes (Kou et al., 2014).

Typically, shoots are harvested for consumption when the first leaves have fully expanded and before the true leaves have emerged; they generally have higher concentrations of human health promoting components such as vitamins, minerals, antioxidants and phenolics than mature plants or seeds. They are harvested just above the roots and consumed fresh as salad greens (Kou et al., 2013), offering a variety of novel greens available in the market, and are typically distinguished categorically by their size and age (Pinto et al., 2015). They are not only produced commercially, but can be cultivated individually in each household for both recreation and own consumption. They can be sown either solely or mixed, or even mixed after harvest in order to balance the dish's flavour and/or appearance. Microgreens are easily cultivated in gardens, balconies, living rooms, and kitchens, or anywhere where the essentials of plant growth are provided. The growth media can be soil, peat, vermiculite, perlite, or bark (Kou et al., 2013). Paper, which has become a highly recommended medium for growing microgreens, can significantly reduce potential risks of contamination and may thus be widely adopted among citizens.

Different media, like soil, peat and vermiculite, can be used for microgreen production; however, soils are prone to contamination and soil-borne pathogens which can be a barrier for household and commercial acceptance. In order to get rid of the problems generated through soil, paper was chosen as a clean medium. With proper management, paper can completely replace soil and produce the same or even better quality microgreens.

Relevant experiments are conducted by the NIBIO research team.

Figures presenting the technology or process

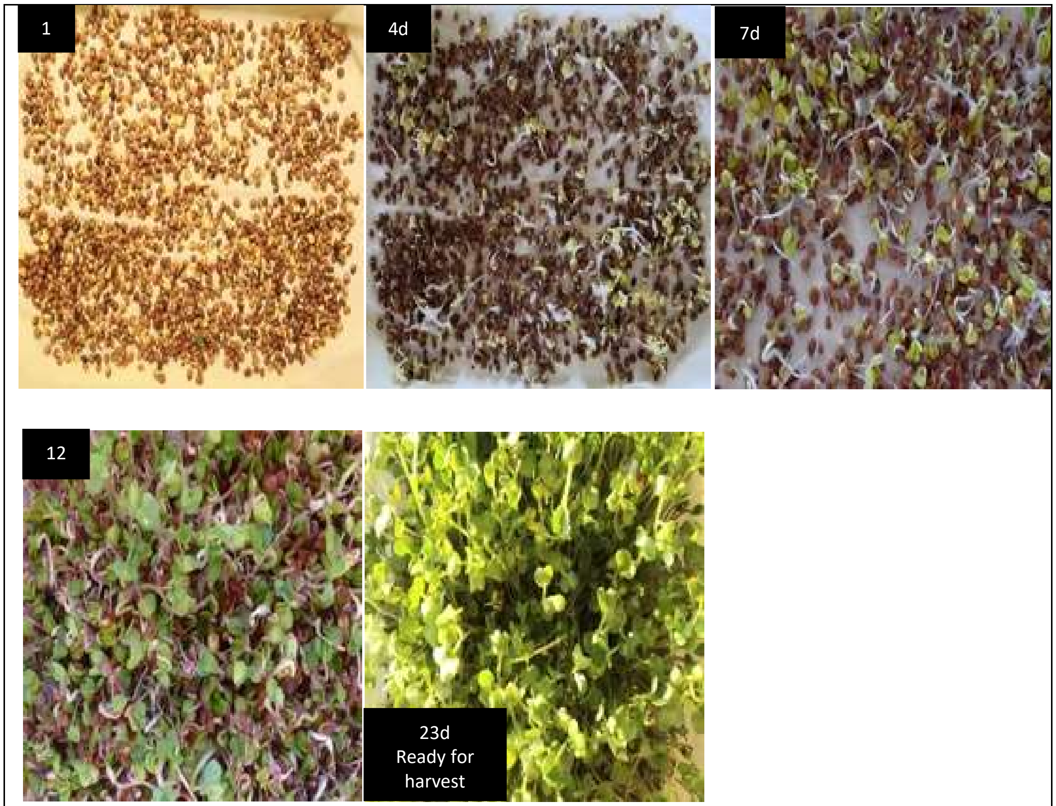


Figure 1. Dikon cultivated on paper towel.

Figure 2. Microgreens in the living room.

Figure 3. Green beans grown in the greenhouse.

Challenges with implementation in the urban setting

Parameter	Low	Medium	High	NA*
Space requirement	X			
Plant growth			X	
Time scale		X		
Regulation				X
Public acceptance			X	

*NA = data not available or not relevant

Special issues needing to be considered when growing microgreens

Light effects on the growth of microgreens: Noichinda et al. (2007) reported that low intensity fluorescent light increased fresh weight loss of Chinese kale (*Brassica oleracea* var. *alboglabra*), but prevented the loss of vitamin C during storage. Lester et al. (2010) observed that continuous light exposure prevented loss of ascorbic acid and was beneficial in enhancing the amounts of carotenoids and tocopherols in baby leaf spinach (*Spinacia oleracea* L.)

Mould has to be removed and discarded as soon as it is observed to prevent further contamination.

Falling over: most likely due to the lack of water

Germination: Roots of microgreens die in the air rather than grow downwards, especially when they are grown on paper or a very shallow medium. Microgreens thrive when they have a weight source to force them to dig their roots deep down into the medium. Adding an even weight on top of microgreen seeds can force the crop's roots to penetrate the pad instead of snaking across it, and to grow much stronger and lift the tray to reach for the light. Air flow is another important parameter that needs to be considered. Seeds should be germinated in the dark, but not in an enclosed space so that the seeds receive fresh air. Third, seeds germinating on top of each other save space and utilize the pressure of weight to facilitate roots' growing downwards into the paper.

Supplementary

Table 1. Crop species suitable for microgreens in the Green Valley Company, Beijing, China, and their corresponding pretreatment length in different seasons

English	**Chinese (中文)**	**Latin name**	**Soaking temperature (°C)**	**Soaking time in summer (hrs)**	**Soaking time in winter (hrs)**
Broad bean	蚕豆	*Vicia faba*	45	30	32
Black soybean	黑豆	*Glycine max* (L.) Merr.	45	12	16
Daikon/Japanese radish	白萝卜	*Raphanus sativus* L. var. *longipinnatus*	45	8	12
Buckwheat	荞麦	*Fagopyrum esculentum* Moench	65	8	12
Chinese mahogany	香椿	*Toona sinensis*	45	18	24
Mung bean	绿豆	*Vigna radiate* L.	45	16	20
Sunflower	葵花	*Helianthus annuus* L.	45	12	16
Grass pea	芸松/草豌豆	*Lathyrus sativus* L.	45	24	30
Snow pea	荷兰豆	*Pisum sativum* var. *saccharatum*	45	12	16

Short description of planned SiEUGreen investigations

How well the microgreens were grown, whether there was any contamination. Questionnaires will be spread to document the acceptance level in households in the future.

Preliminary evaluation of sustainability parameters

Ecological	High	Med	Low	NA*	**Economic**	High	Med	Low	NA*
Treatment performance: Phosphorus			X		Purchase costs			X	
Nitrogen			X		O&M costs				X
Organic matter, SS			X		Cost efficiency	X			
Pathogens				X	Stability	X			
Resource recovery: Nutrients		X			**Social**	X			
Energy			X		Social acceptance	X			
Biodiversity				X	**Technical**				

Landscape aesthetics				X	TRL levels	8-9
Other comments						
Planned for use in showcase	Households in Fredrikstad and greenhouse in Hatay. Microgreens can be tested in the living room, kitchen and balcony, as they are not only vegetables but also for recreation.					

*NA = data not available or not relevant

3.2 'Crispy' lettuce production in NFT system

Growth system	'Crispy' lettuce production in NFT system
Resources	Nutrient film technique - NFT, seeds, nutrient solution
Expected products	Lettuce salad
Green-blue reuse options	Nutrient solution is circulated
Short description of technology Hydroponics has been a standard method for food production (Prazeres et al., 2017) because of its advantages over farming in the soil, like cleanness, less chemical contamination, easy water and fertilizer control etc. Non-invasive estimation of lettuce fresh biomass is of great value as farmers obtain optimal biomass without damaging the lettuce physically. Lettuce head projected area extracted from images has shown its potential in lettuce fresh biomass estimation. Taking advantage of popular deep learning methods, UNET is able to simultaneously segment the lettuce head and reference, estimating lettuce projected area afterwards. The involvement of deep learning enables quick estimation of lettuce fresh biomass. It can also be widely accepted when implemented as an app in mobile phones. The 'Crispy' lettuce plants grew well (Fig. 5) and accumulated biomass exponentially (Figs. 6-7) in a simple NFT setup in the controlled greenhouse. UNET was successfully used to segment the lettuce head from the background. There was an excellent relationship (R^2 = 0.904) between head projected area and head fresh biomass of this 'Crispy' lettuce (Fig. 9). The experiments were done by the NIBIO research team.	
Figures presenting the technology or process	

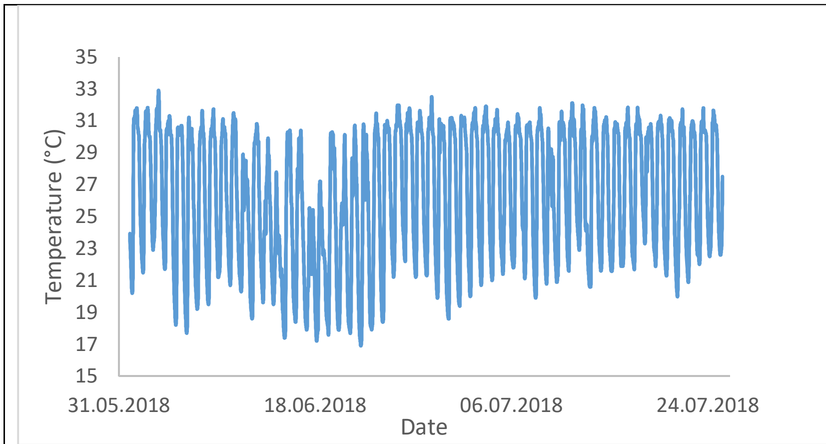


Figure 4. Temperature during lettuce growth period in the greenhouse.

Figure 5. System at the beginning of the trial 25/06/18 (left) and at the end of the trial 09/07/18 (right).

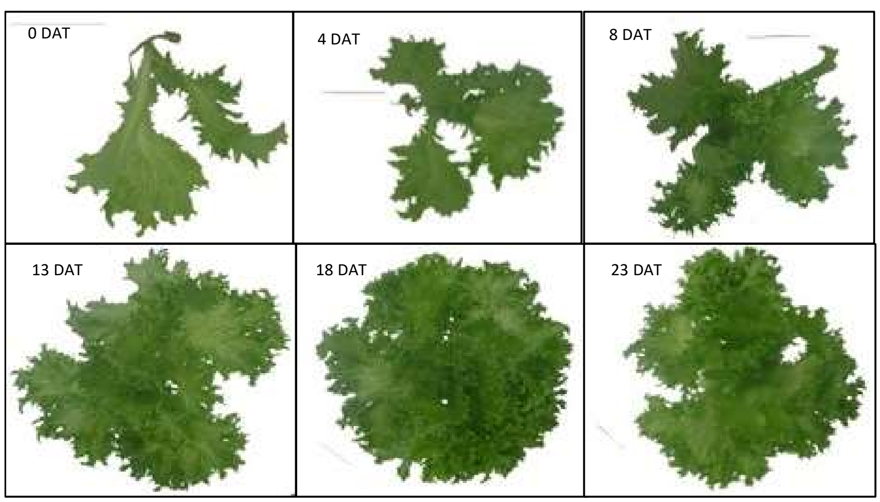


Figure 6. Plant head size at 0, 4, 8, 13, 18, and 23 days after transplantation (DAT).

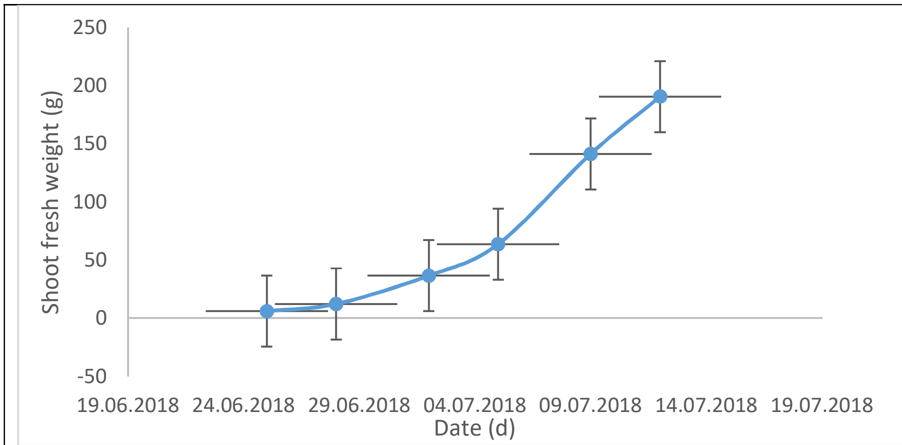


Figure 7. Lettuce head fresh weight at 0, 4, 8, 13, 18, and 23 days after transplantation (DAT).

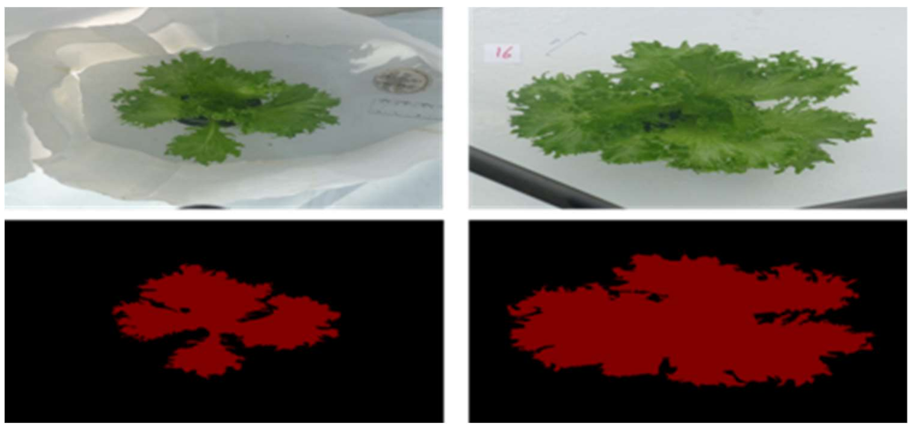


Figure 8. Segmented leaves with U Net method.

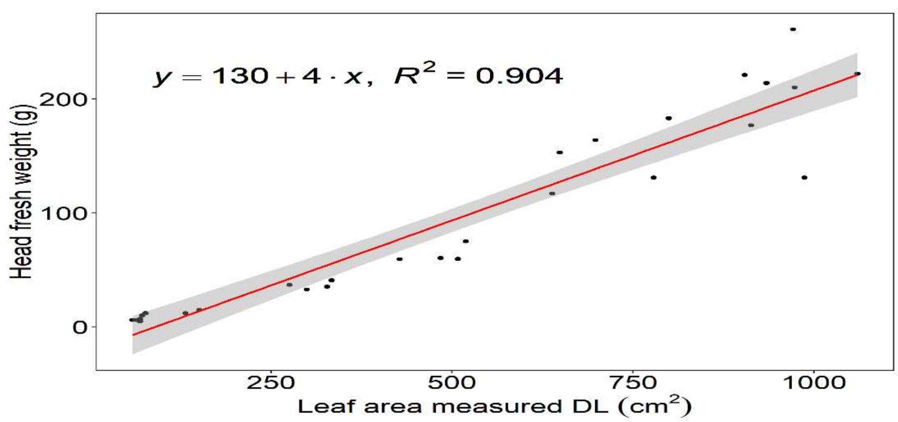


Figure 9. A linear model derived from projected area and the fresh weight of 'Crispy' lettuce head.

Challenges with implementation in the urban setting

Parameter	Low	Medium	High	NA*
Space requirement	X			
Plant growth			X	
Time scale		X		

Regulation				X
Public acceptance			X	

Short description of planned SiEUGreen investigations

The same setup can be used in implementation. Non-invasive ways of quickly predicting lettuce fresh biomass using imaging methods will also be applied. More automatic methods will be developed.

Preliminary evaluation of sustainability parameters

Ecological	High	Med	Low	NA*	**Economic**	High	Med	Low	NA*
Treatment performance: Phosphorus	X				Purchase costs			X	
Nitrogen	X				O&M costs				X
Organic matter, SS				X	Cost efficiency	X			
Pathogens				X	Stability	X			
Resource recovery: Nutrients		X			**Social**				
Energy			X		Social acceptance	X			
Biodiversity				X	**Technical**				
Landscape aesthetics				X	TRL levels	8-9			

Other comments	
Planned for use in showcase	Greenhouses in Fredrikstad and Hatay. Same setup and methods in lettuce fresh biomass prediction will be applied. Nutrient solution prepared can be replaced by biofertilizers recycled in the city.
Last updated	27.06.19 JLC

*NA = data not available or not relevant

3.3 Lettuce production in floating systems with different light conditions

Growth system	A floating system for Butterhead lettuce production
Resources	Nutrient solution, seeds, a floating system
Expected products	Healthy and appealing Butterhead lettuce
Green-blue reuse options	Nutrient solution is circulated during lettuce cultivation with continuous adjustment of EC and pH

Short description of technology

A floating system is another type of hydroponics popular for vegetable production. Plant roots are totally merged in nutrient solution, so oxygen suppliers should be ready to ensure plant health with proper root respiration. Light sources are always of interest to grower as light is the driver of photosynthesis while plants' growth responses to light spectra vary. LED lights consume much less energy (up to 70%) compared to traditional light sources (Singh et al. 2015) while being capable of providing customized spectrum and intensity combinations. Photosynthetic pigments have different sensitivities to light spectra. Finding the best spectrum composition is one of the hot topics in improving plant productivity.

Both fresh and dry weight at two harvest time points, 22 (Figs. 13-14) and 36 (Figs. 16-17) days after transplantation (DAT), were significantly higher in red light illuminated lettuce plants. The chlorophyll content indicator, NDVI, was only significantly higher at 22 DAT (Fig. 15) in lettuce plants grown under white light conditions. Red light is prone to stimulate biomass accumulation as the receptor of red light plays an important role in plant growth and development, agreeing with published results. The lower NDVI in higher biomass lettuce plants indicates that chlorophyll content is not the only parameter determining plant photosynthetic rate and plant growth. Lower chlorophyll content also makes lettuce look less green than conventionally grown ones, which might be less appealing to consumers. Plant growth, diseases or nutrient deficiency should be recorded through images. Further optimization will be done according to the problems met during implementation. The experiments were done by the NIBIO research team in NIBIO's Særheim station.

Figures presenting the technology or process

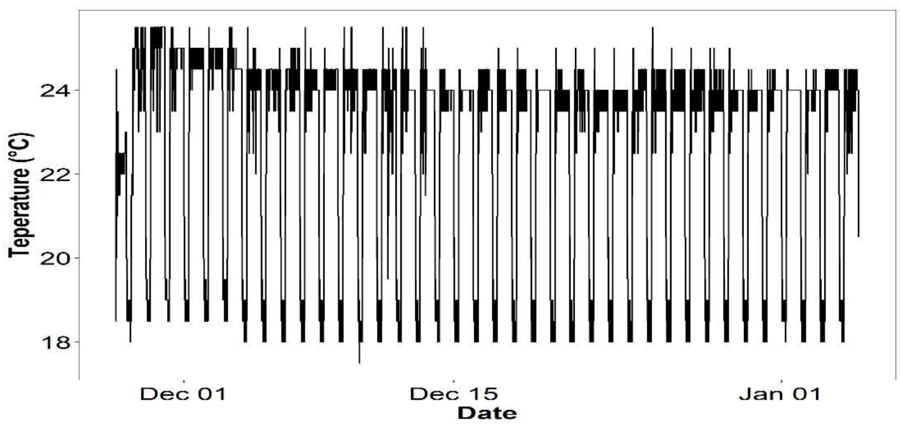


Figure 10. Temperature in the growth chamber during the experiment (recorded every 15 minutes).

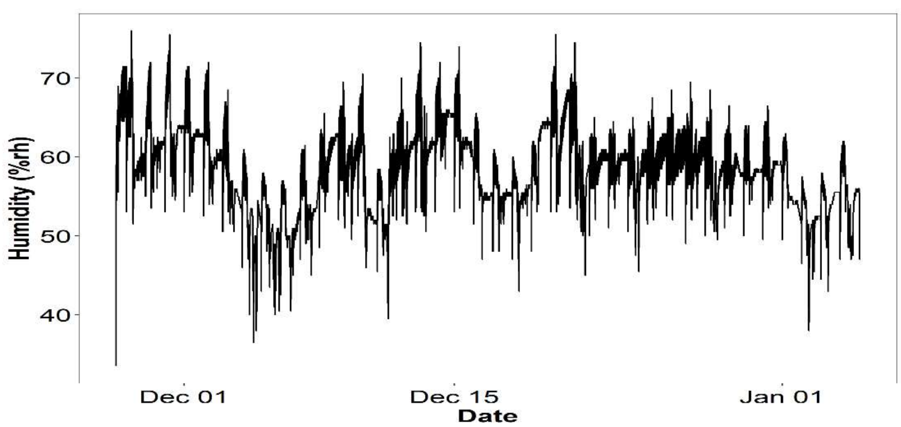


Figure 11. Humidity in the growth chamber during the experiment (recorded every 15 minutes).

Figure 12. Lettuce grown in floating systems with red (left) and white (right) light conditions.

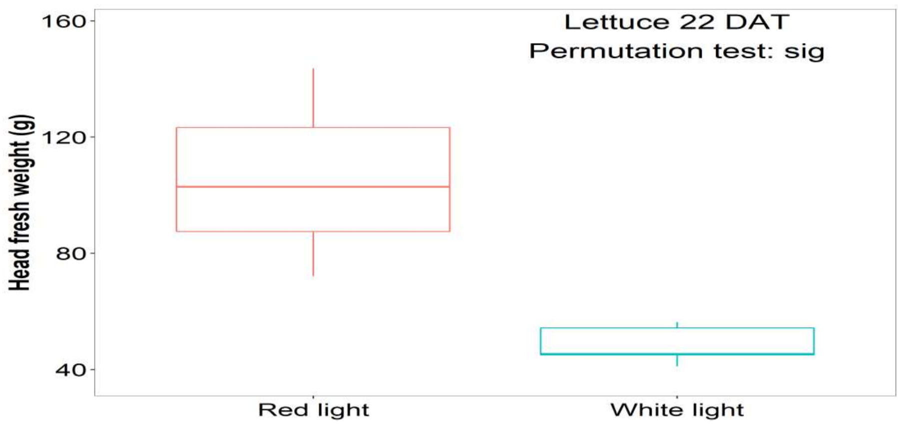


Figure 13. The fresh weight of 22 days' old lettuce head was significantly higher than under white light conditions; p<0.05 in permutation test.

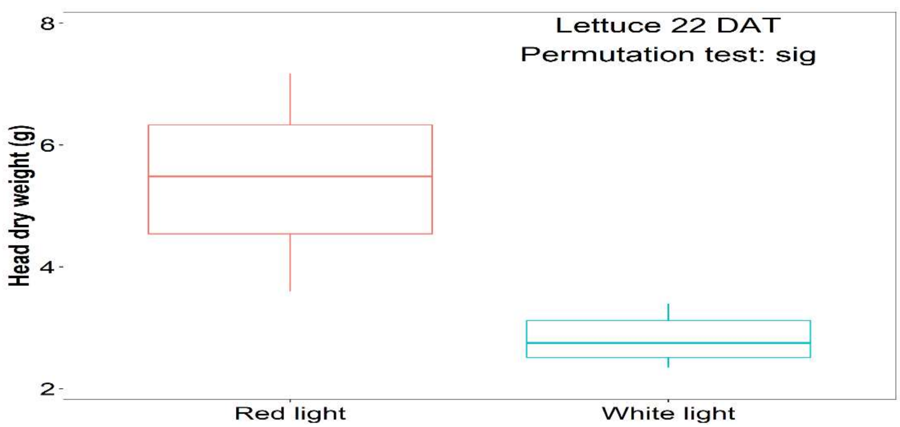


Figure 14.The dry weight of 22 days' old lettuce head was significantly higher than under white light conditions; p<0.05 in permutation test.

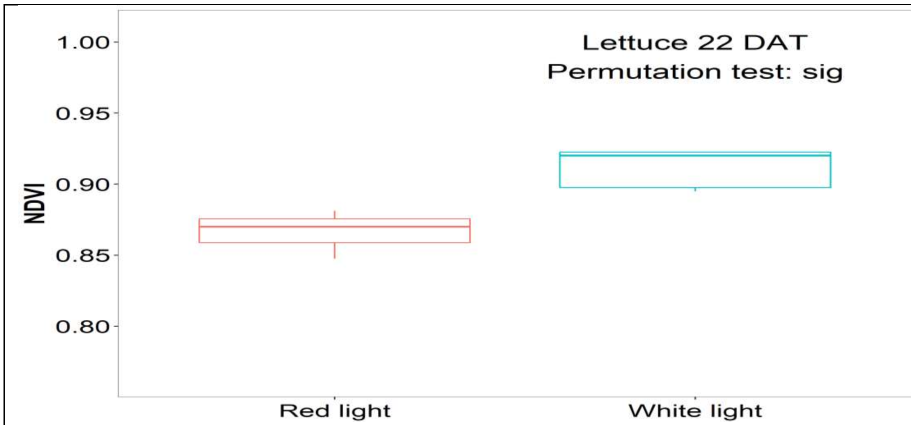


Figure 15. NDVI of 22 days' old lettuce was significantly higher than under white light conditions; $p<0.05$ in permutation test.

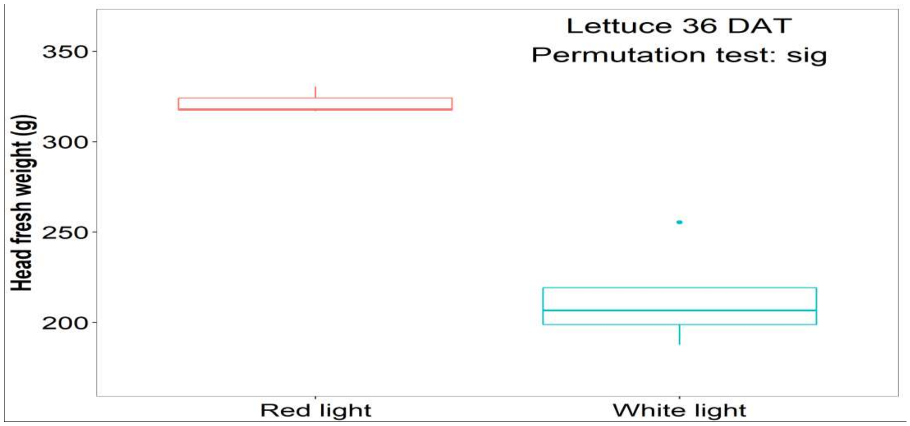


Figure 16.The fresh weight of 36 days' old lettuce head was significantly higher than under white light conditions; $p<0.05$ in permutation test.

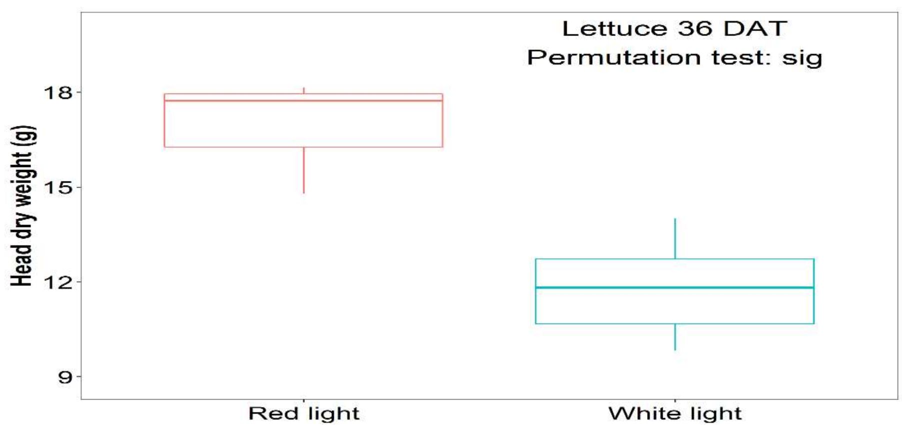


Figure 17. The dry weight of 36 days' old lettuce head was significantly higher than under white light conditions; $p<0.05$ in permutation test.

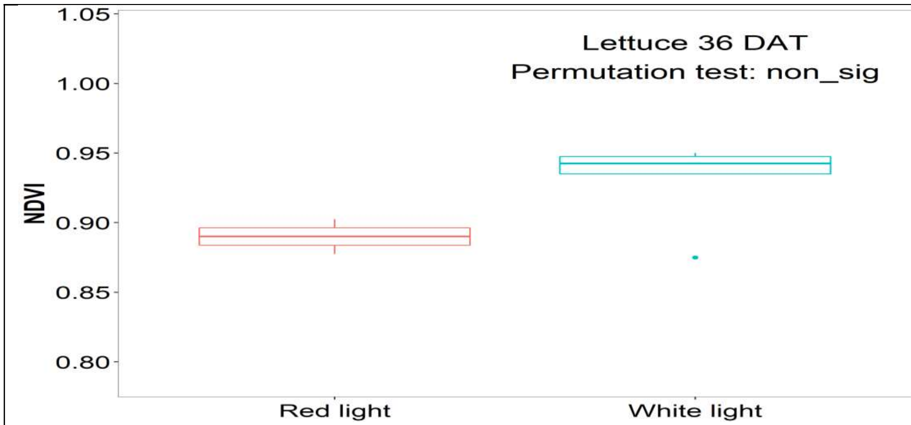


Figure 18. NDVI of 36 days' old lettuce head was significantly higher than under white light conditions; p<0.05 in permutation test.

Challenges with implementation in the urban setting

Parameter	Low	Medium	High	NA*
Space requirement		X		
Plant growth			X	
Time scale		X		
Regulation				X
Public acceptance			X	

Special issues

Limestone or another oxygen supplier should be provided to ensure root respiration.

Short description of planned SiEUGreen investigations

Red light is more effective in fresh biomass stimulation while blue light is beneficial for chlorophyll production. Different proportions of red and blue light will be combined to produce higher fresh biomass while at the same time improving the green colour.

Preliminary evaluation of sustainability parameters

Ecological	High	Med	Low	NA*	**Economic**	High	Med	Low	NA*
Treatment performance: Phosphorus	X				Purchase costs			X	
Nitrogen	X				O&M costs				X
Organic matter, SS			X		Cost efficiency	X			
Pathogens				X	Stability	X			
Resource recovery: Nutrients		X			**Social**				
Energy			X		Social acceptance	X			
Biodiversity				X	**Technical**				
Landscape aesthetics				X	TRL levels	8-9			

Other comments	
Planned for use in showcase	Ready to be used in Fredrikstad and Hatay . Red and blue light with a higher proportion of red light will be used in the showcases in order to stimulate biomass accumulation and produce lettuce that are appealing to consumers. The nutrient solution can be replaced by biofertilizer provided there are enough nutrients.

Last updated	27.06.19 JLC

*NA = data not available or not relevant

3.4 Cucumber production in floating system and rock wool

Growth system	Cucumber production in hydroponics with either water or rock wool growth media
Resources	Rock wool, prepared nutrient solution, floating system, cucumber seeds
Expected products	Cucumber
Green-blue reuse options	Nutrient solution is collected for further processing

Short description of technology

Growth media also vary in different hydroponics techniques; rock wool being one of the most popular ones as it can provide a balanced composition of nutrient solution and air, ensuring healthy plant growth. However, rock wool itself has a high pH, thus hindering water and nutrient uptake due to the restricted root growth (da Silva et al. 1994). It is interesting to study a floating system in order to compare potential advantages of water over rock wool in cucumber physiological status and yield. In addition, oxygen suppliers should be ready for proper root respiration in a floating system.

Stem fresh weight, total leaf area, total above ground biomass and NDVI of 40 DAT cucumber grown in water were significantly higher than those of plants grown in rock wool (Figs. 21, 23, 25, 26). Neither leaf fresh weight nor yield was significantly different between plants grown in water and rock wool even though leaf fresh weight was generally higher in plants grown in water (Figs. 22, 24).

Careful monitoring of the climate conditions is necessary as cucumber is a heat loving species. Plant growth condition and yield should be recorded for investigation. The experiments were done by the NIBIO research team in NIBIO's Særheim station.

Figures presenting the technology or process

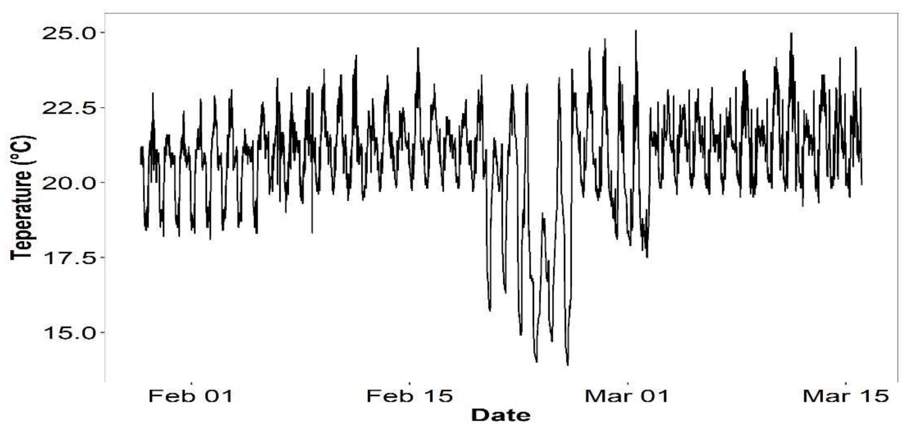


Figure 19. Temperature of the greenhouse during the experiment (data recorded every 15 minutes).

Figure 20. Cucumber growing in a floating system (left) and rock wool (right).

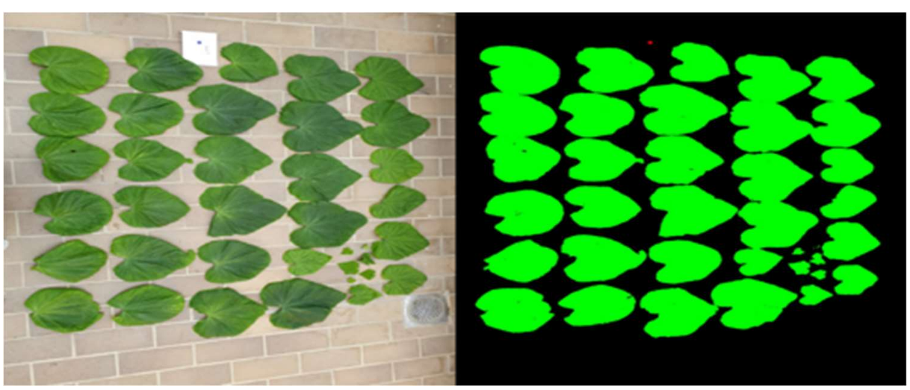


Figure 21. Thresholding methods in segmenting leaf (green) and reference (red).

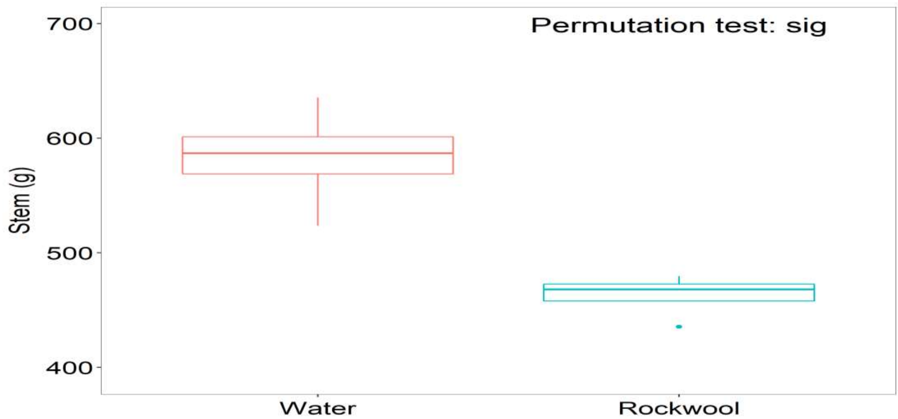


Figure 22. Significant differences in stem fresh weight between water and rock wool growth media; $p<0.05$ in permutation test.

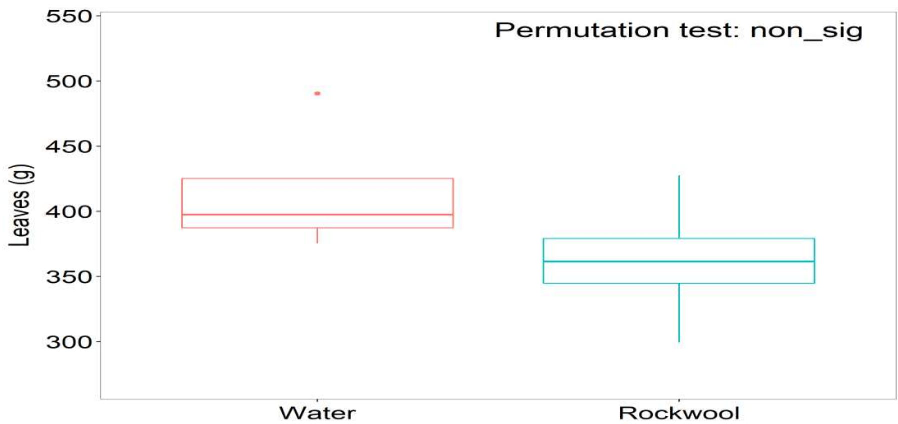


Figure 23. Non-significant differences of leaf fresh weight between water and rockwool growth media; $p<0.05$ in permutation test.

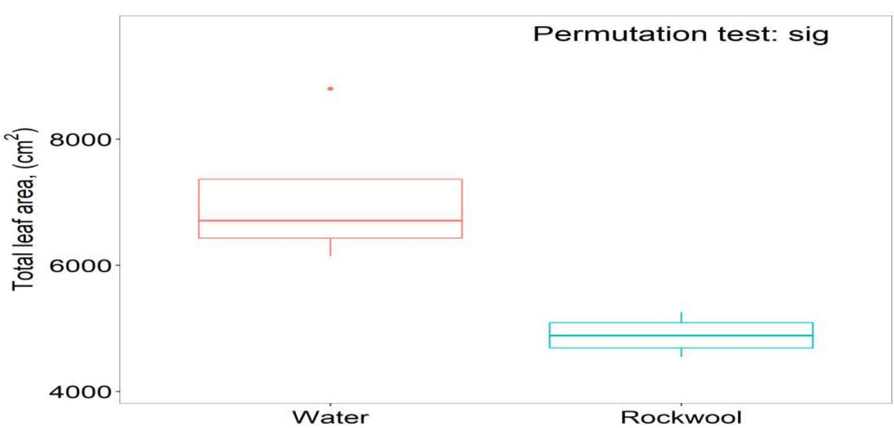


Figure 24. Significantly higher total leaf area in cucumber plants grown in water than in ones grown in rock wool; $p<0.05$ in permutation test.

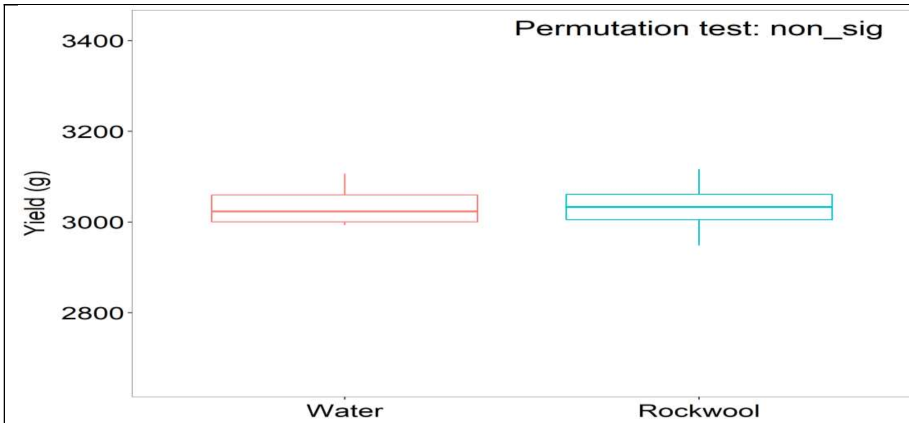


Figure 25. Non-significant differences in yield between water and rock wool growth media; p<0.05 in permutation test.

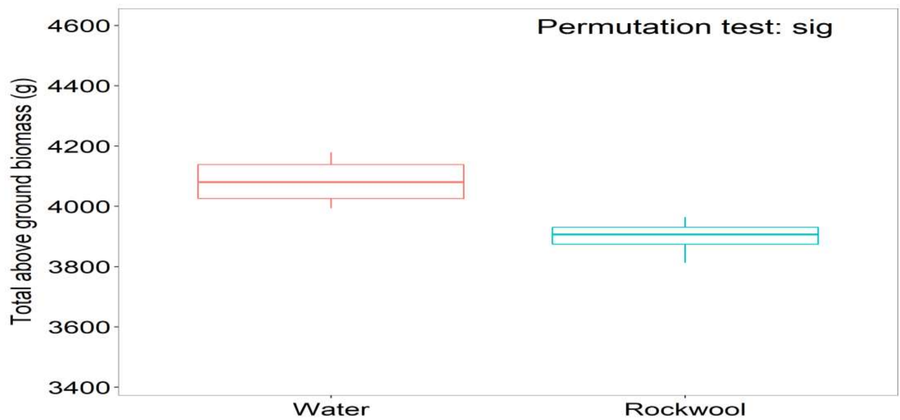


Figure 26. Significant differences in total plant fresh weight between water and rockwool growth media; p<0.05 in permutation test.

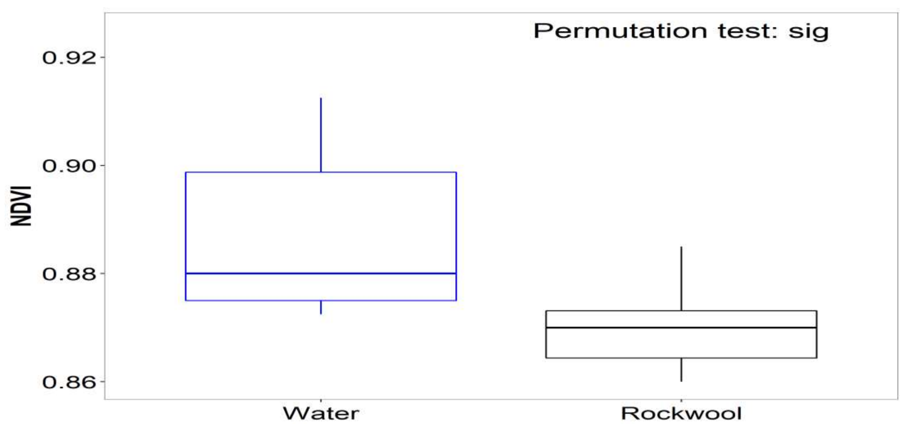


Figure 27. Significant differences in NDVI between water and rock wool growth media; p<0.05 in permutation test.

Challenges with implementation in the urban setting

Parameter	Low	Medium	High	NA*
Space requirement		X		

Plant growth			X	
Time scale		X		
Regulation				X
Public acceptance			X	

Special issues

Limestone or another oxygen supplier should be provided to the floating system to ensure root respiration.

Short description of planned SiEUGreen investigations

The floating system was superior in leaf and chlorophyll production. Cucumber cultivated in a floating system will probably have higher yield as the experiment was stopped in the middle of the growing season. It would be interesting to investigate for the full season and provide a complete report on the advantage of the floating system over rock wool.

Preliminary evaluation of sustainability parameters

Ecological	High	Med	Low	NA*	**Economic**	High	Med	Low	NA*
Treatment performance: Phosphorus	X				Purchase costs			X	
Nitrogen	X				O&M costs				X
Organic matter, SS			X		Cost efficiency	X			
Pathogens				X	Stability	X			
Resource recovery: Nutrients		X			**Social**				
Energy			X		Social acceptance	X			
Biodiversity				X	**Technical**				
Landscape aesthetics				X	TRL levels	8-9			

Other comments	
Planned for use in showcase	Ready to be used in Fredrikstad and Hatay. The floating system shall be adopted and tested in a larger scale for confirming the benefits. The nutrient solution can be replaced by biofertilizer provided there are enough nutrients.
Last updated	27.06.19 JLC

*NA = data not available or not relevant

3.5 Comparison of 'Crispy' lettuce grown with different light conditions in both hydroponics and aquaponics

Growth system	Comparison of 'Crispy' lettuce grown with different light conditions in both hydroponics and aquaponics
Resources	Floating system, aquaponics, fish, fish feed, biofilter, prepared nutrient solution
Expected products	Lettuce
Green-blue reuse options	Nutrient solutions in both aquaponics and hydroponics are circulated
Short description of technology	

Hydroponics has been a standard method for food production (Prazeres et al., 2017) because of its advantages over farming in the soil, like cleanness, less chemical contamination, easy water and fertilizer control etc. Aquaponics is a system that integrates fish production into hydroponics (Klinger and Naylor, 2012): plants utilize the nutrients released from the fish waste by microorganisms and the cleaned water is recirculated for fish production. The key part in aquaponics is the biofilter full of microorganisms that convert ammonium to nitrite for plant use. At the same time, a major complication lies in the pH in aquaponics compared with hydroponics, the optimal pH for fish being between 7 and 9 (Rakocy et al., 2006) while it is between 5.5 and 6.5 for plants (Hochmuth, 2001).

Due to this complication, plants might not be able to grow healthily as ions might precipitate, resulting in plant nutrient deficiency in alkaline solutions. Various results have been published in the literature regarding the production of fish and plants: similar lettuce yields in aquaponics and hydroponics (Pantanella et al., 2012) while tomato yield was significantly lower in aquaponics compared with hydroponics (Graber and Junge, 2009). We compare the production of lettuce in two different cultivation systems, conducting experiments in both hydroponics and aquaponics. At the same time, different light spectrum compositions were chosen to check whether the unfavourable conditions in aquaponics and/or hydroponics could be altered by additional or different light sources.

NDVI of plants was generally higher in hydroponics compared with in aquaponics in both LED light and sunlight conditions, even though not significantly (Fig. 29). Yield of lettuce was significantly higher in hydroponics under LED light conditions, while higher but not statistically so under normal sunlight conditions (Fig. 30).

The experiments were done by the NIBIO research team in NIBIO's Landvik station.

Figures presenting the technology or process

Figure 28. Lettuce growing in hydroponics and aquaponics under high pressure sodium (right) or LED (left) lights.

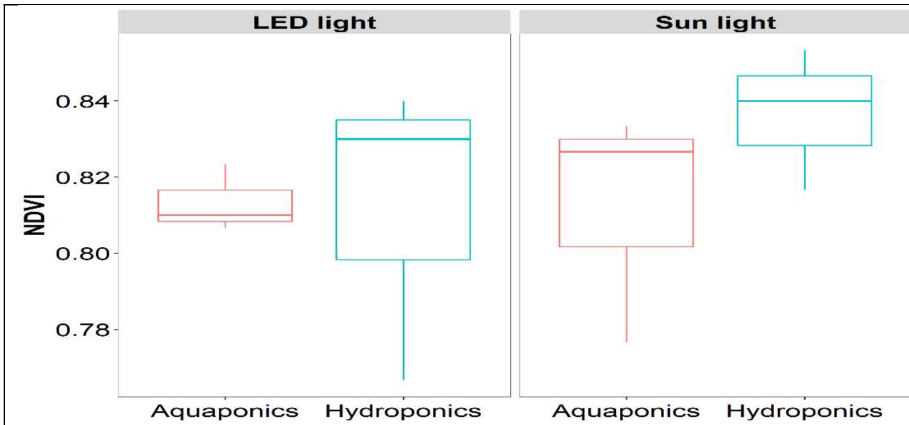


Figure 29. NDVI of lettuce grown in aquaponics and hydroponics under both LED and sunlight conditions.

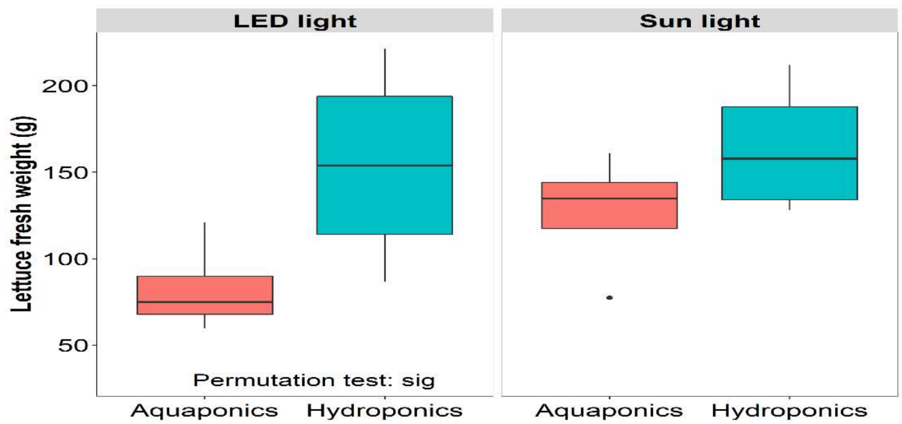


Figure 30. Fresh weight of lettuce grown in aquaponics and hydroponics under both LED and sunlight conditions.

Challenges with implementation in the urban setting

Parameter	Low	Medium	High	NA*
Space requirement		X		
Plant growth			X	
Time scale		X		
Regulation				X
Public acceptance			X	

Special issues

Limestone or another oxygen supplier should be provided to the floating system to ensure root respiration.

Short description of planned SiEUGreen investigations

Hydroponics was a better platform in supporting lettuce growth. Further investigation will be done to check the missing beneficial factors promoting lettuce production in our aquaponics system.

Preliminary evaluation of sustainability parameters

Ecological	High	Med	Low	NA*	**Economic**	High	Med	Low	NA*
Treatment performance: Phosphorus	X				Purchase costs			**X**	
Nitrogen	X				O&M costs				X

Organic matter, SS	X				Cost efficiency	X			
Pathogens			X		Stability	X			
Resource recovery: Nutrients		X			**Social**				
Energy			X		Social acceptance	X			
Biodiversity				X	**Technical**				
Landscape aesthetics				X	TRL levels	6-7			
Other comments									
Planned for use in showcase	Ready to be used in Fredrikstad and Hatay. Different designs or filter systems will be implemented to meet the needs of lettuce or other vegetable production in aquaponics. The hydroponic system is ready to be implemented.								
Last updated	27.06.19 JLC								

*NA = data not available or not relevant

3.6 Hydroponic system for the kitchen bench "Den Lille Gartner"

Resources	Nutrient film technique (NFT) in hydroponics. Can reuse struvite, cleaned water and energy of the resources in the showcase.
Expected products	Lettuce on the kitchen bench in a circulating growth system with pump and light provided for the inhabitants' own consumption.
Green-blue reuse options	If possible (i.e. hygienic enough), the reuse of greywater in the kitchen. An enriched solution with recycled nutrients (e.g. struvite) can be used.

Figure 31. Clear variety/genus differences in the green lettuces grown in the hydroponics system for the kitchen; A: 'Pok Choi', B: 'Little Gem', C: 'Crispy'.

Short description of planned SiEUGreen investigations

The nutrient film technique (NFT) and hydroponics are advanced technologies for the experienced professional greenhouse grower. The balancing of nutrients can be a difficult act to follow for the average citizen. As seen in Fig. 31, there is an obvious difference in the growth of 'Pok Choi', 'Little Gem' and 'Crispy'. The latter seems to be the best choice of the ones we have tried, and it is also a popular commodity in the shops. 'Pok Choi' and 'Little Gem' both suffered from both inner and outer tip burn. Inner tip burn is caused by calcium deficiency, possibly due to the humidity being high resulting in lack of water flow through the plant (https://viken.nlr.no/fagartikler/31245/)

https://ag.umass.edu/greenhouse-floriculture/photos/hydroponic-lettuce-tipburn

We will probably not recommend this technology for our showcase for two reasons: 1) The relatively complicated initiation of the plantlets (seeds need to be germinated in the dark in a small sponge), and 2) when checking the website of "Den Lille Gartner" in May and June 2019, this system is no longer available for purchase**,** so it is not possible to recommend it for our show cases.

Preliminary evaluation of sustainability parameters

Ecological	High	Med	Low	NA*	**Economic**	High	Med	Low	NA*
Treatment performance: Phosphorus				X	Purchase costs		X		
Nitrogen				X	O&M costs				X
Organic matter, SS				X	Cost efficiency			X	
Pathogens				X	Stability	X			X
Resource recovery: Nutrients, energy, water			X		**Social**				
Energy			X		Social acceptance	X			
Biodiversity				X	**Technical**				
Landscape aesthetics				X	TRL levels	WILL NOT BE USED			

Planned for use in showcase	Not planned.
Last updated	29.06.19 THE

*NA = data not available or not relevant

3.7. Buckets with drip irrigation system for balconies or roof top vegetable production

Urban plant production on balconies is not new; the novelty with our approach is the combination of testing growth systems with growth media obtained from recycling organic wastes from the kitchen and sanitary systems. We have tested a much used cultivation method for tomatoes in hobby greenhouses, large buckets (30 L) with drilled bottom holes for drainage and drip irrigation on a timer system, for either watering or nutrient solutions to maintain enough water and nutrients. This system was set up in the NMBU greenhouses in summer 2018 to evaluate growth media, comparing 100% organic compost (household waste: vermicompost 65:35) with peat based medium. The summer of 2018 was extremely hot in northern Europe and the plants suffered in the heat. As a result of some of these challenges (more cracked fruits, particularly in peat and for one susceptible variety), we decided to also test out another system for plant growth with self-watering containers (18 L growth medium and 9 L water/nutrient reservoir for each plant) for the summer of 2019.

Treatment option/process	Bucket with drip irrigation system
Resources	Compost from gardens/households and biogas reactors to be used as growth medium as an alternative to peat

Expected products	Vegetables suitable for buckets – tomatoes, cucumbers, chili, sweet pepper, melon, aubergine, sweet potato for inhabitants' own consumption
Green-blue reuse options	Use of recycled organic wastes from kitchen and garden waste and possibly composted digestate from biogas reactors of the sanitary wastes

Short description of technology

Peat based growth medium has received a lot of negative attention in recent years, due to CO_2 emissions and rapid degradation. Cleary et al (2005) calculated that Canada's consumption, transport and processing of peat, mainly for the greenhouse industry, increased by 66% over the ten-year period from 1990-2000. Furthermore, it would take 2000 years to restore the land. Consumers in Norway are asking for non-peat growth media for their gardens. So far, commercial growers have been reluctant to give up peat, as this is a reliable growth medium, which they master and which has consistent quality. In order to prepare for more urban agriculture by citizens in urban areas and prepare for the transition from peat to compost also for commercial greenhouse growers, we have started a series of experiments to elucidate on any encountered problems using compost for the amateur gardener for a range of crops. Here we have used two varieties of tomato to verify the effects of the choice of growth medium on yields and tomato fruit quality. While waiting for the digestate from the biogas reactors to be ready, we have chosen two commercial growth media product: Tjerbo Gartnerjord, peat with 84 vol. % sphagnum peat, 10 vol. % sand, and 4 vol. % granulated clay, with chalk and dolomite added to reach a pH between 5.5-6.5; compost-based medium from Lindum (www.lindum.no) containing 65% w/w composted household waste and 35% w/w vermicompost made with earthworms to increase nutrient content (Kharrazi et al.2014). The buckets were drip irrigated with either water or nutrient solution provided with an electrical conductivity (EC) of 1.5 ds m^{-1}, to balance a good growth. Both growth media were given the same treatment throughout the experiment.

In the summer of 2018, the tomato varieties 'Golden Sunrise' and 'Alicante' were grown from seeds and potted into 4 L pots with either peat or compost medium until they were large enough to be potted into 30L buckets for both growth media. We have chosen two commercial products; one with 84 vol. % sphagnum peat, 10 vol. % sand, and 4 vol. % granulated clay, with chalk and dolomite added to reach a pH between 5.5 and 6.5. The compost based one contained 65% composted household waste and 35% Vermicompost made with earth worms to increase nutrient content. The pH was 7.0, while the peat based was declared to be between 5.5 and 6.5. The buckets were drip irrigated with either water or nutrient solution provided with an electrical conductivity of 1.5 dS m^{-1}, to provide good, balanced growth. Both growth media were given the same treatment throughout the experiment.

We recorded the yield (number of fruits and weight) and the quality (number of cracked fruits) for each treatment and variety. The experiment was conducted for 3.5 months, from mid-May to the end of August 2018. This was an extremely hot summer, with abnormally high temperatures in the greenhouses.

According to Fig. 32, compost based growth medium was equal to peat with respect to number of fruits (Fig. 32A) and yield (g) (Fig. 32B) for both varieties through the summer. This is a promising result, as it is all we need to be able to make the shift from peat to compost for tomato production. Urban famers can safely grow in nutritious compost. With respect to quality, the compost was far superior to peat for 'Alicante', since the number of fruits with cracks was significantly reduced for this variety (Fig. 32C and D). For 'Golden Sunrise', the problem of cracked fruits under the conditions in the greenhouse was substantial, as seen in Fig. 32C. 'Golden Sunrise' seems to be more vulnerable to fruit cracking compared to 'Alicante', and compost could not sufficiently compensate for this. This is no surprise, as this variety from 1897 is known for thin skin, considered to be an advantage for home grown tomatoes. However, for the thicker skinned 'Alicante', the number of cracked fruits was significantly reduced in compost compared to peat (Fig. 32C and D).

The hot summer of 2018 is probably the reason for the high number of cracked fruits, as irrigation is a crucial component of fruit cracking. High temperatures could cause uneven moisture in the buckets, which is a larger problem for peat than compost since peat is less readily remoisturised. To test this hypothesis, we are repeating the experiment in the summer of 2019, comparing the same experiment in buckets to self-watering containers with a large water reservoir to ensure that the growth medium never dries out.

Figures presenting the technology or process

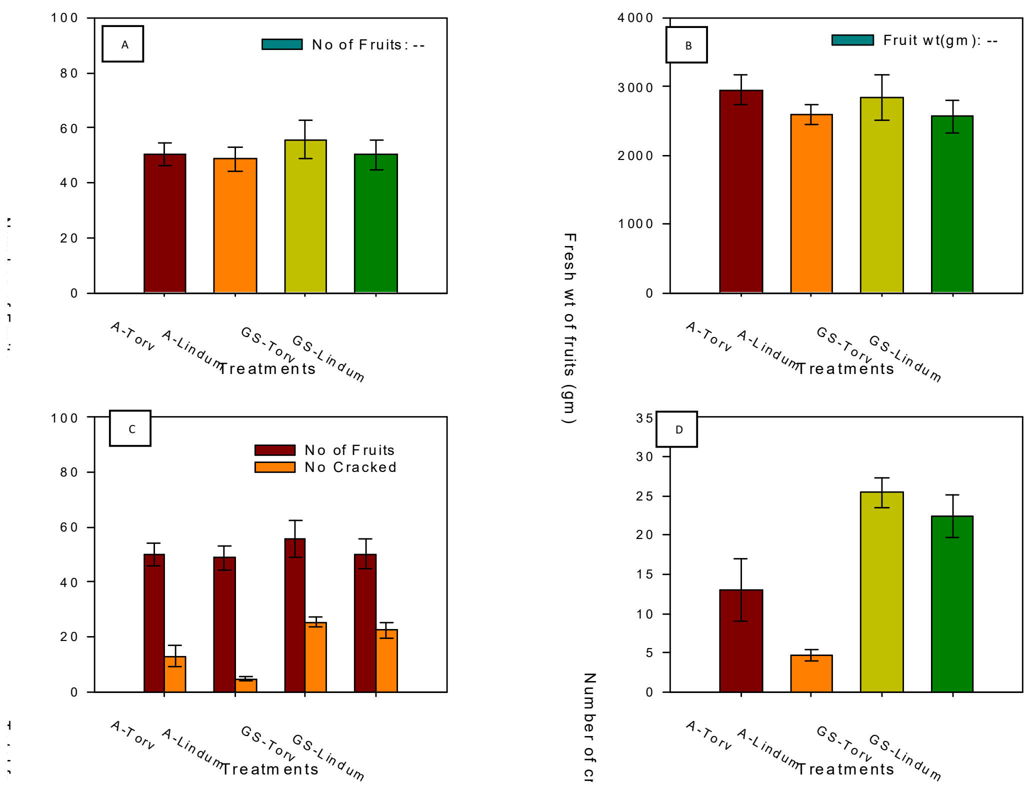


Figure 32. Impact of tomato variety (A='Alicante' and GS='Golden Sunrise') and growth medium (Torv =peat) and Lindum =organic compost) on: A) number of fruits, B) fruit fresh weight (g), C) total fruits vs. cracked fruits, and D) detail for cracked fruits. All numbers are average per plant. Bars represent 5% significance level.

Challenges with implementation in the urban setting

Parameter	Low	Medium	High	NA*
Space requirement	X			
Plant growth			X	
Time scale			X	
Regulation				X
Public acceptance			X	

Short description of planned SiEUGreen investigations

Co-funded by the Horizon 2020 programme of the European Union

Co-funded by the Chinese Ministry of Science and Technology

We will be recommending this system for the inhabitants of the Fredrikstad showcase and will give them a questionnaire to fill in so that we can judge the success of the implementation in 2020.									
Preliminary evaluation of sustainability parameters									
Ecological	High	Med	Low	NA*	**Economic**	High	Med	Low	NA*
Treatment performance: Phosphorus	X				Purchase costs			X	
Nitrogen	X				O&M costs				X
Organic matter, SS	X				Cost efficiency	X			
Pathogens				X	Stability	X			
Resource recovery: Nutrients	X				**Social**				
Energy			X		Social acceptance	X			
Biodiversity	X				**Technical**				
Landscape aesthetics	X				TRL levels	8-9			
Other comments									
Planned for use in showcase	Ready for use in Fredrikstad and Changsha. The scale for demonstration of different types of growth systems would be to include these in the demonstration greenhouse for visitors on or near the showroom/visitor centre on a year-round basis. Tomatoes have indefinite growth and can produce all winter, given enough light by e.g. LED.								
Last updated	29.06.19 THE								

*NA = data not available or not relevant

3.8 Self-watering systems for balcony and roof top cultivation of vegetables (preliminary evaluation, still ongoing trials)

During our search for systems to use, we came across self-watering containers with 18 L growth medium space and 9 L water/nutrient reservoir (Fig. 34). We are testing double and single containers this summer in 2019. So far, these containers are proving very useful and they have shown earlier fruit set only one week after the start of the trial, when compared with the self-watering system (Fig. 33B) with the buckets with drip irrigation from last year (Fig. 33A). We also hypothesise that these containers will be popular with consumers since they do not drip all over the balcony or down to the neighbour below.

Treatment option/process	Cultivation in self-watering systems
Resources	www.plukkselv.no with compost for plant production
Expected products	Vegetables and berries
Green-blue reuse options	Small scale greenhouses, balcony food production

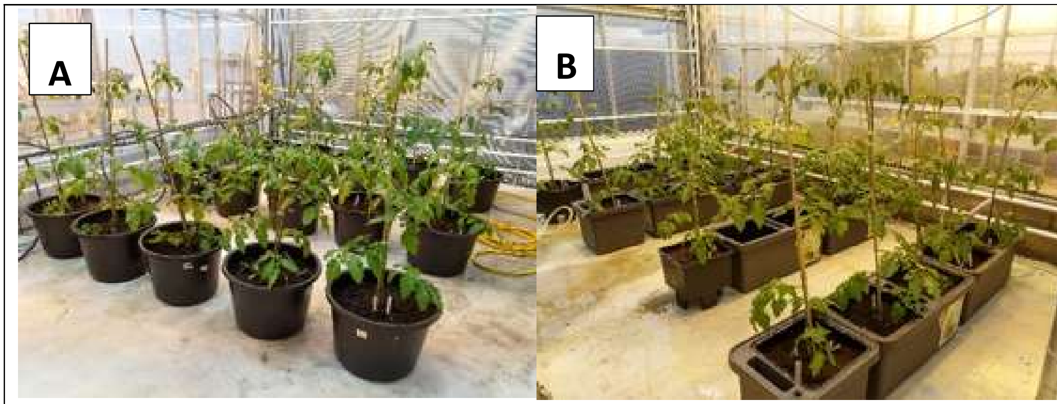


Figure 33. (A) Tomato trial in 30 L buckets in two different growth media; peat based and household/garden waste compost from Lindum, Drammen, Norway. (B) Tomato trial in underwatering system from www.plukkselv.no. Same tomato varieties, 'Golden Sunrise' and 'Tastery', in three different growth media; peat, Lindum compost and compost made from pig digestate mixed with garden waste from NIBIO's trials with a biogas reactor.

Figure 34. Self-watering containers demonstrating the good root growth already two weeks after transplanting into the system. White roots are a sign of a healthy root system. The floater indicating water/nutrient level is the red inside the tube to the left. Behind that, the refill well is placed.

Short description of planned SiEUGreen investigations

This system of self-watering containers will be offered for a reduced price to the Fredrikstad inhabitants and training will be provided. Questionnaires will be handed out to evaluate the success of the technology.

Preliminary evaluation of sustainability parameters

Ecological	High	Med	Low	NA*	**Economic**	High	Med	Low	NA*
Treatment performance: Phosphorus	X				Purchase costs		X		
Nitrogen	X				O&M costs				X
Organic matter, SS	X				Cost efficiency		X		
Pathogens				X	Stability	X			
Resource recovery: Nutrients	X				**Social**				
Energy			X		Social acceptance	X			
Biodiversity	X				**Technical**				
Landscape aesthetics	X				TRL levels	8-9			
Planned for use in showcase	Ready for use in Fredrikstad and Changsha.								

Parameter	Low	Medium	High	NA*
Space requirement	X			
Odour and nuisance				X
Hygiene			X	
Regulation				X
Public acceptance			X	

Comments: the problem of water drip to the neighbour underneath is much reduced with this system. Another very useful thing is that this requires less maintenance and daily attention with watering, as the reservoir has a relatively large capacity. We are monitoring the water use in all three growth media (including composted digestate) in the summer of 2019.

Short description of planned SiEUGreen investigations

Trials have been set up this summer to repeat last year's experiment, and also add treatments with the same variables, but with 'Tastery' instead of 'Alicante' (used in 2018) and using a self-watering system to enable the plants to soak up as much water as they like. We are measuring the same as last year, and in addition how much water/nutrients are used by each plant. We have also, for the first time, been able to test composted pig digestate (from biogas reactor) as another additional treatment. Pigs have the most comparable digestive system to humans and can be used for initial trials while we wait for the Fredrikstad showcase to be established. The experiments are ongoing and look promising with respect to plant health and flower set.

Preliminary evaluation of sustainability parameters

Ecological	High	Med	Low	NA*	**Economic**	High	Med	Low	NA*
Treatment performance: Phosphorus	X				Purchase costs		X		
Nitrogen	X				O&M costs				X
Organic matter, SS	X				Cost efficiency		X		
Pathogens		X			Stability	X			
Resource recovery: Nutrients					**Social**				
Energy			X		Social acceptance	X			
Biodiversity	X	X			**Technical**				
Landscape aesthetics	X				TRL levels	8-9			

Other comments	1) Cost of buckets, the self-watering system medium, is very low 2) A high yield is needed to be cost-efficient to grow your own vegetables
Costs	Ready for use in Fredrikstad and Changsha
Possible use in other showcases	Yes
Challenges This year we are currently (summer of 2019) testing composted pig digestate from the biogas reactors for the first time, as we had to wait for this technology to be ready enough for us to test the products. We need to test this full scale in Fredrikstad next summer (2020) for both tomatoes and cucumber, based on the results we obtain for tomatoes in 2019. Therefore, we are also including comparisons with composted digestate from the NIBIO bioreactors in these self-watering systems. Based on previous research (Nesse et al., 2018), digestate mixed with either coir or paper pulp and used without composting had a too high toxic level for tomato and lettuce. We have therefore composted the digestate for 6 weeks prior to the experiment (described in detail under 3.7). It may be a challenge for the plants to soak up enough water/nutrients with the coarse structure of this first initial digestate compost.	
Last updated	29.06.19 THE

*NA = data not available or not relevant

3.9 Pallet frames for perennial berries for rooftops or backyards

Technology	Pallet frames for perennial crops
Resources	Compost (household: vermicompost)
Expected products	Berries from bushes in double height pallet frames
Green-blue reuse options	Urban farmland, parks and flowerbeds, backyards
Short description of technology The concept of growing plants in pallet frames is by no means new; this is a well established technique for vegetable growth. The novelty in our case is two-fold: the use of pallet frames for perennial crops like blackcurrants is not usual. The second challenge is to use compost as the growth medium and investigate how the bushes respond to this on a rooftop - a very harsh environment indeed, with winds and fluctuating temperatures. We have performed experiments with one cultivar, 'Hedda', of blackcurrant (*Ribes nigrum* L.) over 1.5 years in Oslo (Gardli 2018).	
Figures presenting the technology or process	

Figure 35. Left: the double pallet frames when set up autumn 2017 in "Tak for Maten" roof garden in Oslo. Right: Blackcurrant bushes after one season's growth ready for harvest (Gardli 2018).

Figure 36. Higher amount of garden compost to blackcurrants gave twice as much Vitamin C in the berries of 'Hedda' than the peat growth medium.

Short description of planned SiEUGreen investigations

Using recovered and hygienized plant nutrients from source-separated blackwater and treated greywater, the growth and effects on vegetables and berries will be followed up in the showcase to see if these good results can be reproduced in Fredrikstad.

Preliminary evaluation of sustainability parameters

Ecological	High	Med	Low	NA*	**Economic**	High	Med	Low	NA*

Treatment performance: Phosphorus	X				Construction costs			X	
Nitrogen		X			O&M costs			X	
Organic matter, SS	X				Cost efficiency	X			
Pathogens		X			Stability	X			
Resource recovery: Nutrients Water Energy	 X X			 X	**Social**				
Energy				X	Social acceptance	X			
Biodiversity	X				**Technical**				
Landscape aesthetics	X				TRL levels	8-9			
Other comments									
Planned for use in showcase	Ready for use in Fredrikstad and Changsha.								
Possible use in other showcases	Yes								
Last updated	27.06.19 THE								

*NA = data not available or not relevant

3.10 Evaluation of alternatives to peat in urban agriculture

Treatment option/process	Compost as alternative to peat in plant growth systems
Resources	Compost from gardens, household waste and brown water
Expected products	Quality growth media for horticultural production and urban farming
Green-blue reuse options	Greenhouse, urban farmland, balcony food production, parks and flowerbeds
Short description of technology One major contributor to reducing GHG emissions is to reduce the amount of peat used in horticulture (Cleary et al. 2005). We have been testing alternatives to peat in all the technologies for soil based culture: the kitchen bench "Den Lille Gartner Maxi" for herbs, the 30 L buckets with irrigation holes for tomatoes. We are testing the self-watering system this summer. Finally, we have tested the first year of a perennial crop (blackcurrant) in various compost mixes compared to peat. This summer, we have included composted digestate in our trials, but the results are not ready yet. **Conclusions on alternatives to peat:** In all systems, the compost based mixes have proven to be either equal to, or superior to, peat as a growth medium for herbs, tomatoes and blackcurrants. These plants have very diverse requirements for their nutrition and demand for a stable growth medium; still, they all respond favourably to different combinations of compost. The ultimate proof will be how laymen in the show	

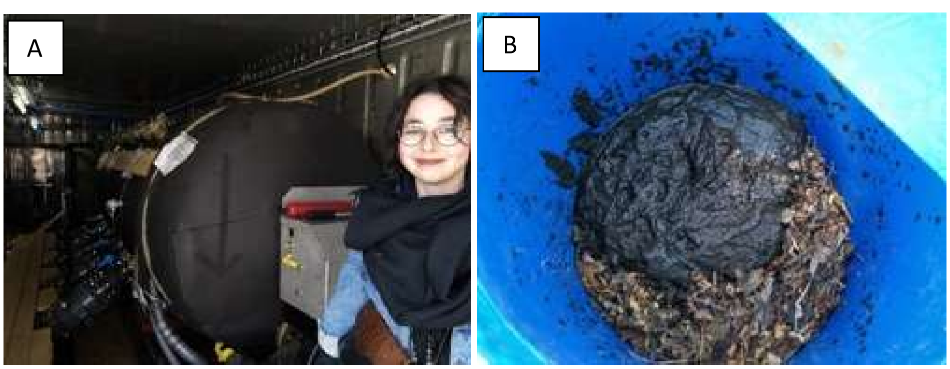
cases will handle the same systems, as they normally do not have an education to back them up. We will train them, monitor their motivation and progress, as well as evaluate their crops.

It is our firm belief that the horticultural industry needs to improve their performance on carbon emissions and finding good alternatives to peat is highly topical in this last week of June 2019 at the III International Symposium on Growing Media, Composting and Substrate Analysis in Milan, Italy. The symposium is, interestingly enough, sponsored by peat producers. They are obviously also aware that a change is on its way. **The challenge is** to provide the industry with a substrate which is **as good as peat in all its qualities and is of consistent quality**.

The barrels with the mix were left to compost in the warm conditions in the container with the biogas reactor for 6 weeks. The mix was regularly turned around to secure aerobic conditions for the composting process. For the same reason, the barrels were aired through draining excess fluids during the process by boring holes in the barrels. Seed tests show that germinating thyme and coriander as indicators for toxicity was efficient. Plants grown in peat germinated quickly, as expected because nutrients were very much available, but turned yellow after 4 weeks when nutrients were depleted. We knew the Lindum tomato compost (Fig. 37) would be too nutritious and the seeds had slow germination, but wanted to include this for comparison. After 4 weeks, Lindum plants were doing well. In the case of the composted digestate, we were unsure as to whether the seeds would germinate at all, due to toxic residue in the digestate. However, even if a little slow in the beginning (Fig. 37, picture taken after two weeks), these turned out to be the best; green and flourishing by the end of the four week period. Both compost media probably had more nutrients in total (samples are being analysed at the moment) and had a slow release of nutrients which better suited the herbs in the long run. This may explain why the herbs purchased in supermarkets quickly deteriorate at home: they are grown on easily available nutrients in peat in the greenhouse and upon arrival in our homes may be on the brink of depletion.

All in all, this gives us a good indication that the composted pig digestate is better suited for vegetables and herbs than the non-composted used by Nesse et al (2018) which had a lot of toxic residues affecting lettuce and small tomato plants (they did not grow them till they fruited) when digestate was mixed with coir or paper pulp and used directly. Our experiments with tomatoes over the whole summer where yield and tomato quality, visible as well as nutritional, will be analysed will give us much more information on the usefulness of this fertiliser product for urban agriculture. So far, the results are promising.

Figures presenting the technology or process of composting pig digestate from bioreactors



Co-funded by the Horizon 2020 programme of the European Union
Co-funded by the Chinese Ministry of Science and Technology

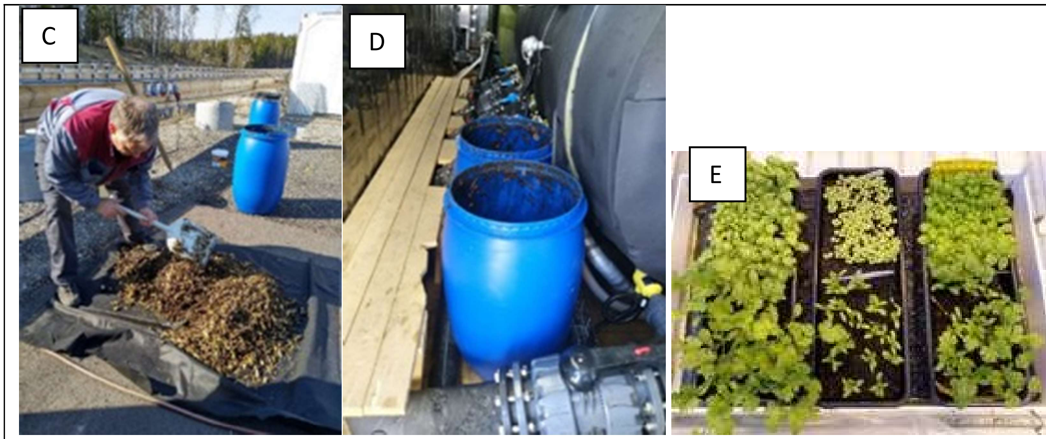


Figure 37. A: NMBU Master student Prune Lacotte next to the biogas reactor. B: 40 kg coarsely ground garden waste (branches and leaves) about to be mixed with 20 L pig digestate from the biogas reactors. C: Roar Linjordet (NIBIO) mixing well before composting. D: Barrels with the mix left next to bioreactor. E: Testing for toxicity using herbs in a seed test. On this panel left: peat, middle Lindum tomato compost and right composted digestate.

Challenges with implementation in the urban setting

Parameter	Low	Medium	High	NA*
Space requirement	X			
Odour and nuisance	X			
Hygiene			X	
Regulation		X		
Public acceptance		X		

Comments:

Short description of planned SiEUGreen investigations

The project will implement alternatives to peat in the showcases, first of all in Fredrikstad. Since we already have good alternatives, we are not dependent upon the use of digestate in Fredrikstad. If the process of handling the digestate is difficult for any reason and alternative use of the digestate makes more sense, we can still provide the inhabitants with compost from Lindum. Some of them might prefer Lindum to their own locally produced. This will be important to follow up by the social scientists to assess attitudes to brownwater products. Social acceptance will be investigated.

Preliminary evaluation of sustainability parameters

Ecological	High	Med	Low	NA*	**Economic**	High	Med	Low	NA*
Treatment performance: Phosphorus	X				Purchase costs			X	
Nitrogen	X				O&M costs				X
Organic matter, SS	X				Cost efficiency	X			
Pathogens		X			Stability	X			
Resource recovery: Nutrients		X			**Social**				
Energy			X		Social acceptance				
Biodiversity	X				**Technical**				
Landscape aesthetics	X				TRL levels	>7			

Other comments	Social acceptance will be monitored by WP1 (NIBIO), before, during and after implementation in Fredrikstad. The use of human wastes may be a social challenge and an interesting case to follow.
Planned for use in showcase	Fredrikstad and Changsha, and in all cases where growing medium is needed, also for soil improvements in backyards and parks.
Possible use in other showcases	Yes

*NA = data not available or not relevant

3.11 Effect of kitchen waste compost on the growth and quality of Chinese cabbage

Treatment option/process	Effect of kitchen waste compost on the growth and quality of Chinese cabbage
Resources	Coconut chaff, kitchen compost, plant material, water
Expected products	Nutrients from compost, vegetables
Green-blue reuse options	Protocols experimented with can be used in cultivation of different vegetables and fruits

Short description of technology

In this experiment, coconut chaff is using as growing medium, compost from kitchen waste is used as fertilizer.

Table 4 Five different treatments on Chinese cabbage

Name	**Description**
CK	Coconut chaff without fertilizer, as control
T1	Coconut chaff with 15 kg/m^3 compost
T2	Coconut chaff with 30 kg/m^3 compost
T3	Coconut chaff with 45 kg/m^3 compost
T4	Coconut chaff with 60 kg/m^3 compost

Each treatment has 5 plants, repeated three times.

Measured indices include chlorophyll of leaves, plant height, biomass, root shoot ratio, yield, Vc content, Sugar content.

Results:

The effects of different amount of kitchen waste compost on plant growth, yield and quality are obvious. T2 and T3 treatments showed higher chlorophyll contents than other treatments. Plant height, biomass and yield increases along with the increased fertilizer dose, while the quality indices (Vc and sugar) in T2 and T3 had better performance, especially in T3.

Table 5. Effect of kitchen waste compost on growth, yield and quality of Chinese cabbage

	Chlorophyll of the leaves (SPAD)	Plant height (cm)	Biomass/ plant (g)	Root shoot ratio	Yield (g/plant)	Vc content (mg/100g)	Sugar (mg/g)
CK	26.96 c	5.28 d	0.44 d	0.38 a	2.44 e	3.40 d	13.39 d
T1	31.29 b	12.25 cd	0.95 d	0.35 ab	6.92 d	10.06 c	22.57 c
T2	33.45 a	15.08 c	2.28 c	0.25 c	20.60 c	14.03 a	30.86 a
T3	32.28 a	18.51 b	3.87 b	0.36 a	32.49 b	14.60 a	31.44 a
T4	31.32 b	23.12 a	6.82 a	0.33 b	51.70 a	13.56 b	30.43 b

Challenges with implementation in the urban setting

Parameter	Low	Medium	High	NA*
Space requirement	X			
Odour and nuisance	X			
Hygiene		X		
Regulation		X		
Public acceptance		X		

Comments:

Short description of planned SiEUGreen investigations

The best mixture ratio of coconut chaff and kitchen compost will be found for the cultivation of different vegetables and fruits with the highest yield and best quality as well.

Preliminary evaluation of sustainability parameters

Ecological	High	Med	Low	NA*	**Economic**	High	Med	Low	NA*
Treatment performance: Phosphorus			X		Construction costs		X		
Nitrogen	X				O&M costs			X	
Organic matter, SS	X				Cost efficiency				X
Pathogens		X			Stability	X			
Resource recovery: Nutrients		X			**Social**				
Energy			X		Social acceptance		X		
Biodiversity				X	**Technical**				
Landscape aesthetics	X				TRL levels	8-9			
Other comments									
Planned for use in showcase	Showcases in Europe and China where needed.								

Possible use in other showcases	Yes
Last updated	29.06.19 THE

*NA = data not available or not relevant

3.12 Maxi system for the kitchen bench - "Den Lille Gartner"

Growth system	A complete system of under-watering with boxes for growth medium (of own choice), soaking mats, light and water reservoir provided.
Resources	Compost from bioreactor digestate or mix of garden/vermicompost.
Expected products	Herbs and greens for own consumption by inhabitants.
Green-blue reuse options	Reuse of the bioreactor digestate or garden/household compost locally produced in Fredrikstad.
Short description of technology The greenhouse industry is well acquainted with systems for watering from underneath using soaking mats and a reservoir of water/nutrients. This system has taken this principle and made a small unit for the kitchen (https://www.butikk.denlillegartner.no/produkt/vekstsystemer/det-lille-gartneri-max-svart-2). The unit is 62 cm long, 43.5 cm wide and 43 cm high, and uses less electricity than 60 watts. We have used it for testing the technology for growing herbs and as a unit for comparing peat vs. compost in 12 units at a time. Both peat and compost are adequately soaking water in this system, and the fluorescent tube light source is adequate for plant growth. The spectra for both this system and the hydroponics system are shown in Figure 38.	
Figures presenting the technology or process	

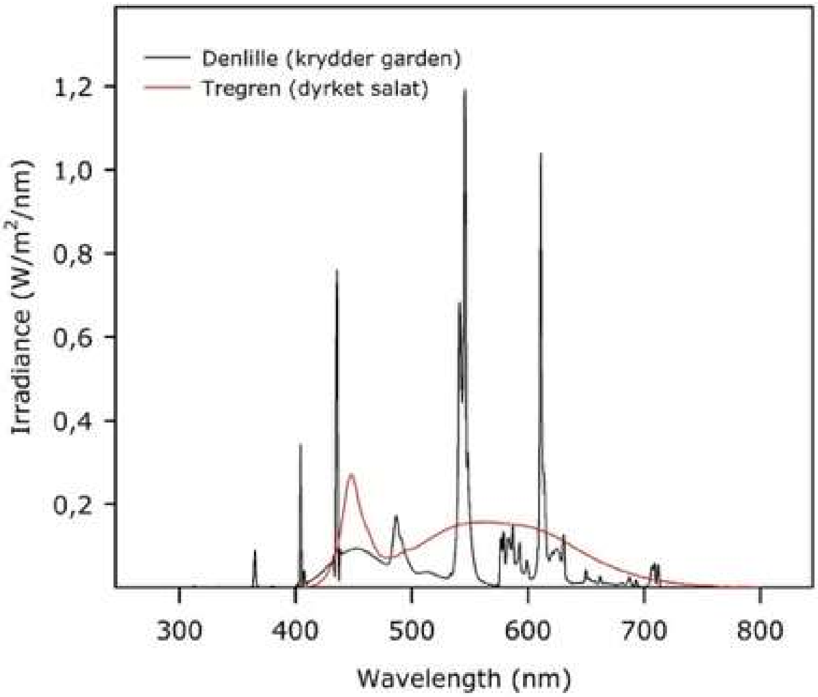


Figure 38. Light spectra from the two growth systems from "Den Lille Gartner". Red line represents the soilless hydroponics system described in 3.1.1. The black line is the Maxi system described above.

In a real life situation, the kitchen would provide more light, from various light sources and possibly also from windows. This would, in fact, be beneficial and increase the usefulness of the growth system.

We have tested five different herbs in this system, four with an equal growth rate: red basil, common thyme, salvia and coriander. Rosemary germinated and grew so slowly that it is not recommended to grow this herb together with the fast growing mentioned above, but in a separate tray.

Instructions on how to use:

The light source can be adjusted and may be low after sowing and raised as the plants grow, always allowing at least 10-15 cm between plants and the light source. Fill the large tray with water (nutrients are not necessary in the beginning), so that there is enough in the growth substrate. Place the soaking mat on top of the platform for the trays and both into the large tray. Then fill the trays with the chosen growth substrate (peat/compost/digestate compost). Then fill the four substrate trays with the chosen growth substrate (peat/compost/digestate compost) and sow the seeds of the chosen herbs thinly. If too dense, the plants will suffer.

Moisturise the growth medium carefully, not to soak too much. Place plastic film on top of the tray to maintain the moisture while germinating. If a seed dries out under the germination process, the seed will die. Let the lamp provide 18 hours of daylight, preferably with a timer to secure enough light every day. When the seeds germinate, the plastic is to be taken off to let the plants grow in normal humidity. Keep the moisture by spraying the first days, until the roots have reached the bottom of the tray and can start soaking up whatever they need. After this, all that is needed is to fill the reservoir with water and after a while a weak nutrient solution to maintain growth. Harvest when needed and let some of the plants remain to sustain regrowth. Herbs can be used fresh, dried or frozen.

In our experiments, the herbs grew best in the compost based growth medium, least in peat. The compost provided darker leaves and sturdier plants with a higher fresh weight.

Figure 39. (A) Under-watering system for "Det Lille Gartneri", (B) production of herbs in this under-watering system for soil/peat/compost.

Conclusions on "Det Lille Gartneri Max"

This system is well suited for indoor production of herbs, as it provides enough light for herbs to grow and thrive, it is easy for the layman with no prior knowledge to master, as the growth medium provides a buffer against too much or too little nutrients. Herbs are well suited, as they do not grow tall (the system would not allow for that) and many people enjoy picking their own herbs in their kitchen. It is a good alternative to herbal plants sold in grocery stores, since these usually wither after a short period of time.

Challenges with implementation in the urban setting

Parameter	Low	Medium	High	NA*
Space requirement	X			
Plant growth			X	
Time scale			X	
Regulation				X
Public acceptance			X	

SiEUGreen investigations

We will be offering this system for the inhabitants of the Fredrikstad showcase and give them a questionnaire to fill in so that we can judge the success of the implementation in 2020.

Preliminary evaluation of sustainability parameters

Ecological	High	Med	Low	NA*	**Economic**	High	Med	Low	NA*
Treatment performance: Phosphorus	X				Purchase costs		X		
Nitrogen	X				O&M costs				X
Organic matter, SS	X				Cost efficiency		X		

Pathogens				X	Stability	X			
Resource recovery: Nutrients	X				**Social**				
Energy		X			Social acceptance	X			
Biodiversity				X	**Technical**				
Landscape aesthetics				X	TRL levels	8-9			
Other comments									
Planned for use in showcase	Fredrikstad and elsewhere, if there is interest. The scale for demonstration of different types of kitchen bench growth systems should include at least one unit in a showroom/visitor centre on a year-round basis.								

*NA = data not available or not relevant

3.13 Urine-based recycling fertilizers for horticultural application: Soil-based and hydroponic experiments

Treatment option/process	Urine-based recycling fertilizers for horticultural application: Soil-based and hydroponic experiments
Resources	Urine, plant material, soil
Expected products	Fertilizers, vegetables, fruits
Green-blue reuse options	Fertilizers can be used in different soil and hydroponic cultivations

Short description of technology

Material and methods**:**

Two nitrified urine fertilizers with differing nitrate/ammonium (NO_3^-/ NH_4^+) ratio were tested in soil-based and hydroponic experiments: 1) Aurin, the Swiss urine fertilizer product produced by the VUNA GmbH with permission for horticultural use in Switzerland and 2) the urine fertilizer product C.R.O.P. developed by the German Aerospace Centre (DLR, *Deutsches Zentrum für Luft- und Raumfahrttechnik*) (Bonvin et al., 2015; Bornemann et al., 2018; Etter et al., 2015) (Table 2). The higher NO_3^-/NH_4^+ ratio of C.R.O.P. is obtained by addition of $CaCO_3$ leading to an increase in pH, thereby promoting a higher nitrification rate.

Table 6. Production factors for Aurin and C.R.O.P.

	Aurin	**C.R.O.P.**
Stabilisation process	Nitrification up to natural equilibrium	Nitrification with addition of a base ($CaCO_3$)
Pharmaceutical/ hormone removal	Activated carbon filtration	In progress

Sanitisation	Distillation/pasteurisation	Pasteurisation
End product	Concentrated urine-based fertilizer solution	Urine-based fertilizer solution with calcium

Soil-based pot experiment: A pot experiment in the climate chamber was conducted, using maize in peat-free substrate. Four fertilizer variants with different N forms and a non-fertilized control were tested (n=5): (1) Aurin, (2) CROP, (3) synthetic urine, and (4) urea. Fertilizer rate was based on crop N demand at flowering. Fertilizers were applied (A) completely and (B) split into two applications (day 0 and after 4 weeks). Additional nutrients required were supplied in an optimum range. Measurements: NH_3 emissions, dry mass (DM) yield, shoot C/N, macronutrients, soil C/N and mineral N.

Hydroponic experiment: We conducted a hydroponic experiment with tomato (L. cv. Pannovy), using the nutrient film technique (NFT) with two urine recycling fertilizers supplementing N in the nutrient solution (Fig. 41): (1) Aurin providing 80 % of N and (2) CROP supplying 100 % of N. The third recycling fertilizer (3) was a combination of Struvite (NH_4MgPO_4) and Vinasse, providing 100 % of the phosphorus (P) and potassium (K) demand in the nutrient solution. All remaining macro- and micronutrients were supplemented to an optimum range. Measurements: Greenhouse gas emissions from the root zone (N_2O, CH_4, CO_2), yield, shoot macronutrients, nutrient depletion rate of solution.

Results and discussion:

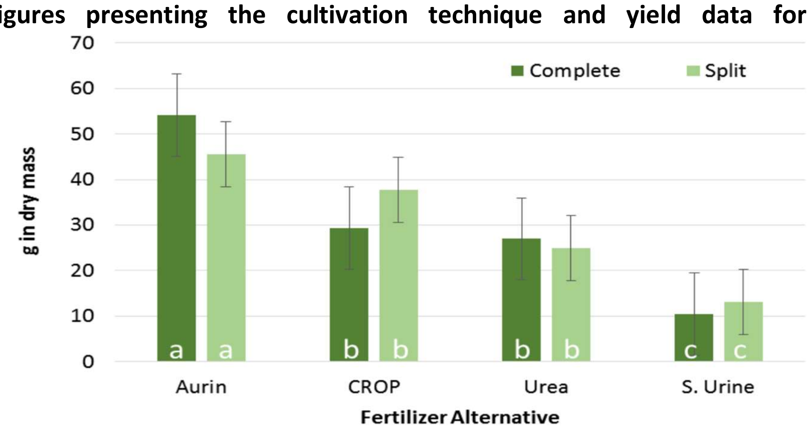
First results of the soil-based pot experiment are shown in Fig. 40. Comparing both nitrified urine fertilizers, dry matter yield was significantly higher with a lower NO_3^-/NH_4^+ ratio (Aurin). Splitting N application rate, as is often done in agricultural practice, did not show any effect on biomass yield. Based on the differences in composition between the two nitrified urine fertilizers (Table 3), assumptions can be made regarding best-practise application for horticulture. Nitrified urine with a high NO_3^-/NH_4^+ ratio was easier to adapt for an ideal hydroponic nutrient solution (e.g. CROP) and could be preferably used for hydroponic applications, as higher NO_3^- concentrations are desired in nutrient solutions. If the NH_4^+ concentration in the solution is too high, it can be toxic for plant roots and increase risk for blossom end rot disease, as also noted in our hydroponic experiment (Aurin treatment). In contrast, a lower NO_3^-/NH_4^+ ratio in urine products (e.g. Aurin) can offer advantages for soil-based systems, as the soil buffers the NH_4^+. The lower NO_3^- share in the urine-based product could decrease the risk of leaching, as NO_3^- is highly mobile in soil. Yet, the risk of ammonia emissions remains, as 50 % of N is present as NH_4^+ in Aurin. In this case application technique and timing should be carefully chosen. Emissions will be further evaluated from the upcoming results.

Table 7. Chemical characteristics of Aurin and C.R.O.P.; values in parentheses indicate standard error of analysis.

	C.R.O.P.	**Aurin**
NO_3-N	4.8 (± 1.4)	33 (± 11)
NH_4-N	1.0 (± 0.5)	33 (± 12)
NO_3/NH_4 ratio	5:1	1:1

P ($g\ l^{-1}$)	0.30 (± 0.09)	2.9 (± 0.7)
K ($g\ l^{-1}$)	1.4 (±0.3)	19.9 (± 4.7)
S ($g\ l^{-1}$)	0.36 (± 0.12)	4.0 (± 1.0)
Ca ($g\ l^{-1}$)	5.2 (± 1.4)	0.8 (± 0.4)
Mg ($g\ l^{-1}$)	0.17 (± 0.04)	0.18 (± 0.10)
Na ($g\ l^{-1}$)	2.1 (± 0.5)	23.3 (± 5.6)
Cl ($g\ l^{-1}$)	3.6 (± 1.0)	47 (± 16)
Fe ($mg\ l^{-1}$)	0.20 (± 0.08)	7.4 (± 5.7)
Zn ($mg\ l^{-1}$)	1.4 (±1.0)	26 (± 20)
B ($mg\ l^{-1}$)	0.9 (± 0.4)	36 (± 26)
Mn ($mg\ l^{-1}$)	2.3 (±0.9)	2.2 (± 1.2)
Cu ($mg\ l^{-1}$)	0.06 (± 0.03)	14 (± 12)

Figures presenting the cultivation technique and yield data for urine-based fertilizers



(a)

(b)

Figure 40. (a) Shoot biomass of maize plants (g DM). "Complete" refers to a full fertilizer application before seeding; and "Split" refers to 50 % of total N before seeding and 50 % of total N after two weeks. Different letters indicate statistically significant differences between alternatives (α < 0.05, Tukey Test) and (b) maize plants after 8 weeks.

Figure 41. Hydroponic experiment at IGZ, nutrient film technique.

Challenges with implementation in the urban setting

Parameter	Low	Medium	High	NA*
Space requirement	X			
Odour and nuisance	X			
Hygiene			X	
Regulation		X		
Public acceptance		X		

Comments:

Short description of planned SiEUGreen investigations

The objective is to examine the use of urine-based recycling fertilizers in soil-based and hydroponic horticultural production systems and to create a proof-of concept for nutrient cycling in circular economy food systems. Our focus is on plant nutrition aspects, growth performance, and greenhouse gas emissions.

Preliminary evaluation of sustainability parameters

Ecological	High	Med	Low	NA*	Economic	High	Med	Low	NA*
Treatment performance: Phosphorus		X			Construction costs		X		
Nitrogen	X				O&M costs			X	
Organic matter, SS			X		Cost efficiency				X
Pathogens			X		Stability	X			
Resource recovery: Nutrients	X				**Social**				
Energy			X		Social acceptance				X
Biodiversity				X	**Technical**				
Landscape aesthetics	X				TRL levels	7-8			

Other comments	
Planned for use in showcase	For use in all cases if results can be verified in repeated observations.

Possible use in other showcases	Yes
Last updated	27.06.19 IGZ

*NA = data not available or not relevant

4. Showcase implementation plan

For the green technology, we plan to roll out the implementation as soon as the inhabitants in showcase Fredrikstad have moved into the first flats.

- SiEUGreen will have an information meeting on the technologies (blue, green and yellow) where the inhabitants will be invited to express their interest in growing their own food.

- NMBU will negotiate a good price for the systems we have evaluated for the inhabitants, so they can order at a discount price in a bulk order.

- NMBU will grow tomatoes, chili and cucumber plants for sale (at a discount price) to the inhabitants who would like to participate in the full scale operational setting. If they pay, they will take more care. If we supply the plants, we have control over the varieties and can compare results more easily.

- NMBU and NIBIO plan to arrange seminars as training courses for the inhabitants who will take part, in indoor, balcony or back yard cultivation during the winter/spring of 2020 to prepare for the growing season outdoors from early/mid-May.

- NMBU will make online courses with the same content, to spread the word around to other cities in Norway and the rest of Scandinavia (who will understand Norwegian).

- NMBU and NIBIO will be available for consultancy through an internet service and whenever we are there to register growth and development of the project.

- We will coordinate our efforts with the social scientists in WP1 to monitor the effect of our training course, both *in vivo* and online.

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