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Department of Crop Production Ecology

How to improve the soilless cultivation of sweet basil looking at light and nutrition?

Hur kan den hydroponiska odlingen av basilika förbättras med olika ljus- och näringsbehandlingar?

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Abstract

Sweet basil of the variety Genovese Gigante is an economically important crop with common use in the gastronomic, medical and cosmetic fields, to name a few, due to the high content of essential oils (EO). Indoor cultivation is a viable alternative to grow sweet basil all-year-round, independent of the outdoor conditions. There is a need to optimize the cultivation conditions for indoor growth in terms of both high productivity and optimal EO content. The study aimed to explore various light and nutrient regimes in order to assess their effects on morphology, growth rate (R_G), EO composition and nutrient uptake of basil grown in a hydroponic system.

Light emitting diode (LED) lights of blue and red were used and to generate various light treatment coloured cellophane are added. The light settings green, yellow and control (no added cellophane) were used. The light settings were combined with two nutrient regimes of the commercial fertilizers ‘Blomstra’ and ‘Hydro A+B’ by Gold Label. After two months of growth the sweet basil was assessed in terms of (a) the morphological and physiological traits plant biomass, height, leaf length and chlorophyll content (SPAD) as well as (b) the contents of EO and (c) the nutrient elements N, P, K, Ca, Na, Mg and S.

The results showed a significant increase in biomass, height, leaf size and SPAD as did nutrient uptake (N, P, K, Ca, Mg, Na, S) and the EO eucalyptol, linalool and eugenol with increasing PAR (green<yellow<control). The results showed no support for greater enrichment of EO in plants undergoing the light treatments of green and yellow light.

Nutrient ratios closest to the recommended concentrations for herbaceous plants were found in ‘Blomstra’ nutrient solution. N:P-ratio in the plants and biomass was negatively correlated for plants grown with ‘Blomstra’, indicating a more optimal concentration of nutrient supply. Lower biomass was found in the plants grown with ‘Hydro A+B’. The higher nutrient levels in ‘Hydro A+B’ could have worked toxic on the sweet basil and limited its growth. A possible trade-off effect was found optimizing for R_G and EO concentrations using the fertilizer ‘Hydro A+B’, concluding that the combination of nutrient elements influences the correlation between biomass and EO. This discovery can practically be implemented in the farming system.

The combination of ‘Blomstra’ fertilizer and control LED-light treatment had over all positive effects on the studied traits of biomass, morphology and physiological traits, nutrient uptake and EO composition. The EO estragole, with antimicrobial properties, was found in high concentrations in a contaminated farming system. Estragole levels could be practically enforced as indicators of pollutants in the cultivation environment when growing sweet basil.

Keywords: hydroponics, aeroponics, sweet basil, essential oils, vertical farming

Sammanfattning

Basilika av sorten Genovese Gigante är en ekonomiskt viktig gröda och vanligt förekommande inom gastronomi, medicin och kosmetik, för att nämna några användningsområden. Detta beror främst på basilikans höga koncentration av essentiella oljor (EO). Inomhus odling är ett praktiskt alternativ för att kunna odla basilika året om, oberoende av förhållandena utomhus. Det finns dock behov att optimera odlingssystem inomhus för att både kunna nå en produktiv odling samt en optimal inlagring av EO. Studien ämnar utforska olika ljus- och näringsregimer för att kunna nå optimal effekt på morfologiska egenskaper, tillväxthastighet (R_G), EO komposition och näringsupptag av basilika i ett hydroponiskt system.

Till belysning används blå och röda lysdioder (LED) som standardljus. Med hjälp av färgat cellofan applicerat på standarsljuset skapas olika ljusförhållanden. I försöket används de tre ljusbehandlingarna grönt, gult och kontroll (utan cellofan). Ljusbehandlingarna kombineras med växtnäring av de två sorterna 'Blomstra' och 'Hydro A+B' av märket Gold Label. Efter två månaders odling skördas basilikan och analyseras utifrån (a) morfologiska och fysiologiska egenskaper; biomassa, höjd, bladlängd, klorofyllinnehåll (SPAD) liksom (b) innehåll av EO samt (c) innehåll av näringsämnena N, P, K, Ca, Na, Mg och S.

Resultatet visade signifikant ökning av biomassa, höjd, bladlängd och SPAD samt ökat näringsupptag (N, P, K, Ca, Mg, Na, S) och ökad koncentration EO eucalyptol, linalool and eugenol med ökande PAR (grön<gul<kontroll). Studien hittade inget stöd för en ökad EO koncentration vid användandet av grönt och gult ljus.

Näringsproportioner närmast de rekommenderade värdarna för örter återfanns i näringslösningen 'Blomstra'. N:P-kvoten påträffad i basilikan och biomassan hade en negativ korrelation för växter odlade med näringen 'Blomstra', vilket indikerar att 'Blomstra' har en mer optimal näringstillgång. Växter som odlades med näringen 'Hydro A+B' genererade en lägre biomassa. 'Hydro A+B' hade högre näringskoncentrationer än det rekommenderade, vilka kan verka toxiskt för basilikan och begränsa dess tillväxt. En positiv avvägningseffekt identifierades för optimering av R_G och EO vid behandling med 'Hydro A+B', vilket indikerar att sammansättningen av näringsämnen påverkar korrelationen mellan biomassa och EO. Upptäckten går enkelt att implementera i den redan existerande odlingen.

Kombinationen av behandlingarna 'Blomstra' och kontroll hade överlag positivt utfall i studiens undersökta egenskaper; morfologi och fysiologi, näringsupptag och EO sammansättning. Estragole är en EO med antimikrobiella egenskaper som påträffades i hög koncentration i ett kontaminerat odlingssystem. Koncentrationer av just estragole skulle därför kunna användas som en indikator för förorening vid odling av basilika.

Nyckelord: hydroponik, aeroponik, basilika, essentiella oljor, vertikal odling

Populärvetenskaplig sammanfattning

Hydroponik har av många ansetts vara framtidens odlingsteknik för sallad och kryddväxter. Eftersom odlingen ofta anläggs inomhus finns det möjlighet att experimentera med växtens miljö för att hitta det bästa sättet att odla på. Industriellt vill man ofta odla en så god växt som möjligt på kortast möjliga tid. I ett försök att möta industrins behov undersökte vilka de bästa ljus- och näringsbehandlingarna är när man odlar basilika inomhus. Genom att använda grönt, gult och obehandlat ljus tillsammans med antingen växtnäringen 'Blomstra' eller 'Hydro A+B', kan jag nu berätta vilken den bästa kombinationen är!

När klimatet runt oss förändras blir det svårare att odla eftersom ingen säsong är den andra lik. För att vara säker på att det produceras mat som räcker till alla behöver innovativa lösningar ta större plats. Hydroponisk odling har av många ansetts vara framtidens sätt att odla. Tekniken finns redan men skulle behöva finslipas för att bli ännu bättre. Odlingsformen innebär att odla växter utan jord. Istället odlas växterna i vatten och flytande näring. För att växten ska stå upprätt odlas den i en kub av stabiliserande medium som rötterna kan tränga sig igenom för att kunna ta upp näring och vatten.

För att försöka odla upp stor, snabbväxande och smakrik basilika är både ljus och näring viktiga delar i odlingspusslet. Det finns tidigare studier som pekar på att basilika som odlats under lampor med färgat ljus smakade bättre. Genom att laborera med grönt, gult och obehandlat ljus kunde studien snabbt konstatera att ljus har en stark påverkan på hur fort basilika växer och smakar. Däremot var det inte det starka gröna och gula ljuset som hade den största effekten på smaken som vi hade hoppats på, utan det obehandlade ljuset. Det var inte färgen i sig som spelade någon större roll utan hur mycket av ljuset som kunde användas till fotosyntesen, PAR (photosynthetically active radiation). Det obehandlade ljuset hade högst PAR, men sjönk i storleksordningen gult och grönt. Ett högre PAR gjorde också att basilikan växte sig större under en kortare tidsperiod. Med det sagt så har många andra studier visat att färgat ljus ska ge mindre men mer smakrik basilika. Jag tror därför att det går att laborera mycket med ljuset för att hitta en optimal strategi för belysning.

De två flytande växtnäringarna visade sig ha mindre påverkan på basilikan vid en första anblick. Basilika odlad med 'Blomstra' visade sig bli större på kortare tid även om 'Blomstra' hade lägre koncentration av näringsämnen än ´Hydro A+B´. Det förvånade oss eftersom vi trodde att 'Hydro A+B' med så mycket mer näring skulle få basilika att växa fortare. Det visade sig vara helt fel. För höga koncentrationer av näringsämnen kan vara giftigt för växter som då kan ta upp för mycket näring på en och samma gång. 'Blomstra' hade en mer lagom koncentration av näringsämnen för just basilika.

Sammanfattningsvis, hitta en näring som matchar växtens behov och belysning som optimerar fotosyntes. I basilikans fall var det kombinationen av 'Blomstra' och obehandlat ljus.

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Abbreviations

B	'Blomstra' nutrient solution
CEC	Cation exchange capacity
DWC	Deep Water Culture
EO	Essential oils
GCMS	Gas chromatography-mass spectrometry
H	'Hydro A+B' nutrient solution
L1	Green Light
L2	Yellow light
L3	Control light
LED	Light emission diode
N	Nitrogen
P	Phosphorus
PAR	Photosynthetically active radiation
R:B	Red:blue light ratio
R:FR	Red:far-red light ratio
R_G	Relative growth rate
SPAD	Chlorophyll content

1 Introduction

The world population keeps growing and food security is becoming more important (FAO, 2017). Especially in urban areas worldwide, populations are expected to double within the next 30 years (Kozai *et al.*, 2016). In Sweden, greenhouse gas emissions and eutrophication of water bodies from agriculture are issues that need to be addressed (Bergström *et al.*, 2015). Vertical farms are presented as an option for complementing traditional agriculture and greenhouse farming due to their optimized use of space and urban local production possibilities.

1.1 Vertical farming

Vertical farming enables the grower to optimize the spatial use of a location area using any cropping system of choice. It is not uncommon to use the conventional farming system growing plants in the medium of soil, geoponics. However, hydroponics has become an interesting alternative to geoponics. The term hydroponics is an umbrella term for different cropping systems where the roots are situated in a nutrient solution, which is aerated with oxygen stones or oxygen pumps (Sör, 2017). One of the simplest hydroponic design is the Deep Water Culture (DWC), which will be used in this study (Figure 1a). Another hydroponic system is the aeroponic cropping system, which by the name indicates its function as an air-water culture cultivation system (Figure 1b). The plant roots are hanging free in a sealed container of high humidity provided by an atomized, pressure spray-nozzles providing the roots with nutrient-enriched water (Lakhiar *et al.*, 2018). Both hydroponics and aeroponics use stabilising medium instead of soil, which in this study was rockwool.

The company Optima Planta Sweden AB situated in Uppsala develop aeroponic systems and grows herbs and vegetables. The aeroponic system has several advantages making it supreme to both geoponics and other soilless systems such as hydroponics and aquaponics. Plants grown in the aeroponic system absorb nutrients and water from a mist of nutrient rich water in an isolated root zone. In the hydroponic and aquaponics systems the roots submerge in a nutrient solution take up nutrients and water. In comparison to conventional systems, aeroponics reduces water resource use by up to 99 %, fertilizer use by 50 % and reduces the growth period by 45 % (NASA Spinoff, 2006). Aeroponically grown vegetables have showed to hold more minerals and vitamins compared to conventionally grown vegetables, making the plants potentially more nutritious and healthier (AlShrouf, 2017). Even though the science is in their advantage, Optima Planta has an interest to evaluate the differences between the plants cultivated in hydroponics and their own aeroponic system systematically.

1.2 Sweet basil

Sweet basil, *Ocimum basilicum L.*, has several different fields of use in medicine, perfume, food industry, etc., and it is the main herb produced by Optima Planta Sweden AB. It belongs to the family Lamiaceae, consisting of herbs and bushes of a wide variety of morphotypes and chemotypes (Lawrence, 1988). The model organism in this study was the variety Genovese Gigante. This variety is known for its rich taste and considered the best variety in the making of the Italian sauce pesto (Miele *et al*., 2001). Each type of sweet basil has its own characteristic aroma based on the genotype and chemical composition of essential oils (EO) (Marotti *et al*., 1996). The EO of plants fall into the two distinct chemical classes of phenylpropanoids and terpenoids, both located in the granular hairs of basil leaves and stems (Miele *et al.*, 2001, Sangwan *et al.*, 2001). The major EO of sweet basil are the terpenoids eucalyptol and linalool together with the phenylpropanoids estragole, eugenol and methyl eugenol (Sangwan *et al.*, 2001). The oil accumulation is dependent on the developmental stage of the plant and the tissue responsible for the accumulation (Sangwan *et al.*, 2001). For the chosen variety of Genovese Gigante, methyl eugenol and eugenol have higher concentration in basil when harvested at a younger age (10-12 cm in height) (Miele *et al.*, 2001). The content of methyl eugenol and eugenol has been linked to plant height in the cultivar of Genovese Gigante, where the amount of methyl eugenol dominated in the smaller plants whereas eugenol dominated in taller plants (Miele *et al.*, 2001). Sweet basil increases its content of EO up to full flowering stage, where linalool is the dominating EO of the full-grown cultivar (Lemberkovics *et al.*, 1995, Sangwan *et al.*, 2001). If harvest occurs before the mature age (35-40 cm in height) the linalool has not yet reached the high concentrations in the plant (Miele *et al.*, 2001).

1.3 Nutrient regime

Many plant quality characteristics and growth traits such as the relative growth rate (R_G, day^{-1}) are controlled by the cropping system and/or the cultivation conditions, including the nutrient and light regimes. In order for plants to reach a maximum R_G all the essential nutrient elements, need to be accessible in a minimum amount. This means that the nutrient element that is least available relative to the plant requirements will have a limiting effect of the R_G, according to Liebig's law of the minimum (Knecht & Göransson, 2004; Liebig, 1840, 1855).

A recent study on sweet basil has highlighted the importance of choosing an appropriate fertilizer composition since the nutrient ratio affects both growth and EO production (Burducea *et al.*, 2018). It is therefore of both scientific and commercial interest to investigate which fertilizers are optimal for the in-door growing of sweet basil. Several experiments have proven the linear dependency of R_G to the concentration of the limiting nutrient. The ratio of nitrogen (N) and phosphorus (P) has a direct influence on the R_G, but the optimum ratio depends on the plant group of similar traits (Knecht & Göransson, 2004). Sweet basil falls under the category herbaceous plants see Table 1 for the specific fertilizer demand of the non-phylogenetic group. As of today, Optima Planta use the fertilizer 'Blomstra' (Cederroth, Upplands Väsby, Sweden) and has never tried another nutrient solution. Could other nutrient solutions, with adjusted element ratios, possibly better suit the needs of growing sweet basil in an indoor cultivation system like the one used by Optima Planta? The two-component nutrient solution 'Hydro A+B' (Golden Label, nutrient composition see table 1) is optimized for various water-based cultivation systems and will be tested here alongside 'Blomstra'. The nutrient composition of 'Hydro A+B' varies compared to 'Blomstra', and an important difference is the N:P ratio in 'Hydro A+B' being considerably smaller than in 'Blomstra' (e.g. Table 1). 'Hydro A+B' was also chosen because the difference in nutrient composition was expected to generate a distinct difference between the two treatments.

Table 1: Optimum nutrient ratios for herbaceous plants suggested by Knecht & Göransson (2004) followed by the ratios of the two nutrient solutions used in the experiment (according to information from the manufacturers).

	N	**P**	**K**	**Ca**	**Mg**	**S**	**N:P**
Herbaceous plants[1]	100	14.3	68.3	8.3	8.7		6.9
Blomstra[2]	100	19.6	82.6	5.7	7.6	7.6	5.1
Hydro A+B[3]	100	54.5	136.4	90.9	45.5		1.8

[1] Herbaceous plant ratio as suggested by Knecht & Göransson (2004)
[2] Blomstra, Cederroth, Upplands Väsby, Sweden
[3] Hydro A + B, Golden Label

1.4 Light regime

Regarding the light regime provided for the sweet basil, light from the red and blue spectral ranges is commonly used in indoor plant production to effectively grow plants. The ratio of red:blue light (R:B) has been shown to affect the resource use efficiency of sweet basil cultivated indoor, suggesting that the physiological response to light quality can be linked to changes in biomass yield and nutrient contents (Pennisi *et al.*, 2019). Optima Planta uses light emission diode (LED) panels of red and blue light to grow their crops with an R:B of 3:1. Various light settings alter the morphology, physiology and quantitative traits of sweet basil depending on light quantity (irradiance) and quality (Stagnari *et al.*, 2018, Pennisi *et al.*, 2019). For light measurements of this study the photosynthetically active radiation (PAR) is used alongside red:far red ratio (R:FR). PAR is a quantum measuring system that designates the amount of light, within the spectral range from 400 to 700 nm, which can be used for photosynthesis by photosynthetic organisms (McCree, 1981). Moving on to the R:FR, plants react to the ratio to regulate their growth according to the season (day/ night length). When looking into ways to generate light settings, Stagnari *et al*. (2018) recently used coloured light of blue, green and yellow to investigate the influence on the morphology, physiology and quality traits of sweet basil. Yellow light stimulated the R_G, due mainly to the provision of higher PAR; and both green and yellow light influenced the composition of EO (Stagnari *et al*., 2018). Various colour settings are expected to generate different PAR which in turn generated different R_G depending on the colour setting. A reduced R_G is expected following a lower PAR.

1.5 Aims and hypotheses

By exploring optimization strategies for both the nutrient and light regimes, this thesis aimed to assess the effects of various light and nutrient regimes on the R_G and other physiological and morphological plant traits, including the contents of EO, to optimise an efficient high-quality cultivation of sweet basil. For the light regime, I expected (*H1*) greater enrichment of EO using the green and yellow light treatment. I also expected (*H2*) that the light regime providing the highest PAR should generate the highest R_G. Leading to the hypothesis (*H3*) of a trade-off between optimizing for high R_G and quality (taste in terms of EO concentrations).

In the hydroponic cultivation system used here, the nutrients were partly taken up from the solution by the plant roots, and partly adsorbed by the growth medium rockwool, which has a low but significant cation exchange capacity (CEC). The rockwool was expected to immobilize a proportion of P. Therefore, for the nutrient regime in the hydroponic culture, I expected the N:P ratio to affect the R_G and that (*H4*) the plants grown in the nutrient solution of 'Hydro A+B' should perform better than the plants grown with 'Blomstra', in terms of R_G. Further, (*H5*) plants grown in the aeroponic system should perform better than the ones grown in the hydroponic system since the roots in the hydroponic system will compete with the rockwool for the nutrients, while the aeroponic system eliminates this competition.

Regarding the accumulation of EO, depending on the biomass, growth and morphology the ratio of methyl eugenol and eugenol was expected to shift (*H6*): The smaller the plant, the higher the ratio of methyl eugenol following the larger the plant the higher the accumulation of eugenol.

2 Material & methods

2.1 Plant material and pre-cultivation method

Prior to the cultivation in the hydroponic or aeroponic systems, plants were pre-cultivated for four weeks in a separate system to develop proper roots. I did the pre-cultivation according to the practice of Optima Planta. Seeds of sweet basil (*Ocimum basilicum* L. cv. Genovese Gigante) were planted in plastic baskets with stabilizing medium of rockwool. Rockwool is the regularly used medium by the company and is used in both the hydroponic system and in the aeroponic system. The medium prevented the plants from tipping, keeping both the root and the shoot in a desirable position. Since the seedlings initially were very small, the amount planted in every basket varied. It was important to keep the seeds well hydrated without suffocating them. The basket was in direct contact with the water surface and allowed for the rockwool to keep moist and for the seed to absorb the water of need. Therefore, the baskets were put in blocks of Styrofoam with cut-out squares to place the baskets in. Every block carried 15 baskets. Four blocks were planted together in the pre-cultivation (60 baskets per system). The pre-cultivation was done in 30 L plastic boxes (IKEA, product "SAMLA") filled with water and some addition of phosphoric acid to lower the pH to 5.5-6.5 (Hochmuth, 2001). A pH-value in this recommended range optimises nutrient uptake of seedlings and plants when grown with nutrients (Hochmuth, 2001). No excessive nutrients were added at this stage. The seedlings were instead supplied with nutrients from the reserves in the seeds. To ensure the growth condition to be optimal, pH and electric conductivity were measured continuously and regulated by adding water and/or phosphoric acid. The herbs were grown in a closed room without any windows, since light and humidity needed to be controlled. Another IKEA box was used for those purposes as two panels were fastened at the bottom of the box. The boxes with the panels were turned upside down and put on top of the bottom-down boxes holding the seedlings, facing the light of the panels towards the seedlings (Fig. 1). Placing the edges of the boxes against each other created a closed system on its own generating a climate of higher humidity as the energy of the light caused the water to evaporate. The end product looked similar to Figure 1a, but without the air pump.

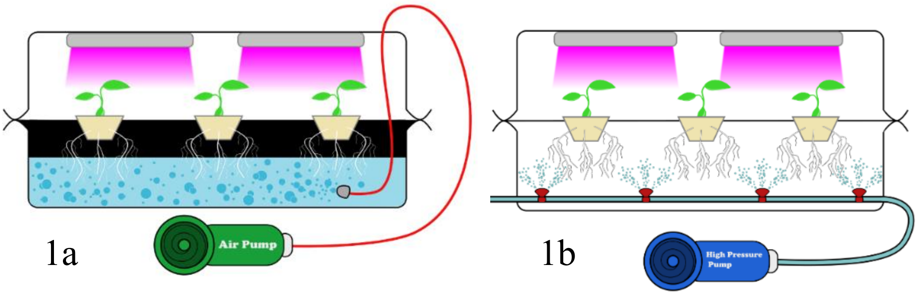

Figure 1: Schematic picture of the soilless cultivation systems. The blue and red diodes created a purple light together from the above fastened LED-panels. Rockwool was used as stabilizing growth medium in the pots. (a) In the hydroponic system the root zone was partly spread in the water and nutrient solution, whilst partly above the water surface in case to reduce the risk of oxygen deficiency. The connected air pump provided the water with oxygen. (b) In the aeroponic system the roots were hanging in the open air of the root zone. The highly humid air surrounding the roots was supplied with water and nutrient solution sprayed in the root zone by nozzles connected to a high-pressure system, pumping the solution in through a larger system of aeroponic growth cambers like the one above. Figure illustrated by Adam Falck.

2.2 Hydroponic system - growth conditions and experimental treatments

After pre-cultivation of the seedlings, the plants were transplanted to the hydroponic cultivation system (Figure 1a). The plants previously grown in the pre-cultivation chambers were randomly planted at new positions in the hydroponic cultivation boxes and exposed to various treatments differing in fertilizer and light supply. In the hydroponic system all the shelfs were given 45 L of water and phosphoric acid to regulate the pH and nutrient solution according to a pre-defined schedule. The same LED-panels were used as in the pre-cultivation stage, but the light irradiance was lower since the plants were physically closer to the light sources.

The treatments were performed in a randomized block design (Figure 2). The light treatments (L1 to L3) were varied by using coloured cellophane of green (L1) and yellow (L2). A third light treatment without coloured cellophane was used as a control (L3). The overall treatments were a combination of light and nutrient regimes (B for ‘Blomstra’, H for ‘Hydro A+B’), in terms of “L1-3+B/H”. The design generated six treatment combinations of light and nutrient regimes, which were replicated three times each creating 18 cultivation boxes in total. Each of the 18 cultivation boxes in the hydroponic systems held 20 plants.

The baskets were transplanted into darkened cultivation boxes to prevent algae and photosynthesising bacterial growth in the water. The upper part of the root zone was hanging free in the air while the root tips were in the water. An air pump of the model "envir-o aeration pumps", model ET60 was used to oxygenate the water and prevent the roots from oxygen deficiency. After 3-4 weeks of growth, the sweet basil had reached a mature age and was harvested.

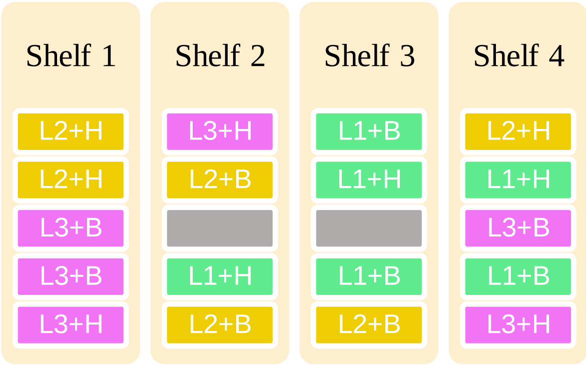

Figure 2: Schematic outline of the experimental design, showing the randomized locations of the various treatments differing in light (L1 green, L2 yellow, L3 control) and nutrient regime (B 'Blomstra', H 'Hydro A+B').

2.2.1 Fertilizer regime

Fertilizer is a resource that must be available in enough quantity for the plant to grow continuously and for the plant not to lose its functions. According to the routine procedure applied by Optima Planta, the nutrient solutions were prepared from a balanced, complete fertiliser, 'Blomstra', with NH_4^+ and NO_3^- in the proportion 2:3 (nutrient composition see table 1). 'Blomstra' acted as a control for the nutrient treatments. The second fertilizer used was the two-component fertilizer 'Hydro A+B'. 'Hydro A+B' was chosen since it was a recommended product for hydroponic cultivation. The 'Hydro A+B' solution had a higher ratio of P compared to 'Blomstra'(Table 1).

The doses of nutrients were based on the given growth scheme of 'Hydro A+B'. Since the nutrient concentrations and ratios varied between the two nutrient solutions used (Table 1), the solution with the higher N concentration, i.e. 'Hydro A+B', was slightly diluted to achieve similar N supply in the two nutrient treatments.

2.2.2 Light regime

The lighting consisted of two panels of LED-diodes per hydroponic chamber, situated approx. 12 cm above the plants. The panels only used the diodes from the blue and red light spectrum, since chlorophyll a and b mainly absorb light from these spectral ranges (Evert *et al.*, 2013). The LED-diodes were spread on a 3:1 ratio distribution of R:B. Length of daily photoperiod was controlled by a timer setting 8 h light, 30 min dark (to prevent flowering which is sensitive to photoperiod), 7 h 30 min light and 8 h dark per day.

The specific colour regime was chosen after consulting Stagnari *et al.* (2018). In this study, green, blue and yellow light were found to cause a difference in the R_G and EO composition of sweet basil. The method of adding coloured film was an easy and cost-efficient way of regulating the light settings and was therefore used. Since the space of experiment was limited, the blue light was neglected from this study, since it was expected to generate a much slower growth. The three light settings of green, yellow and control were measured in PAR (using MQ200 Quantum Flux, Apogee) and R:FR (using SpectroSense 2, Skye instruments) to better understand how the light may influence the R_G, nutrient uptake and EO composition.

2.3 Aeroponic system – Design and implementation

Optima Planta managed the aeroponic cultivation of sweet basil in their regular production system (Figure 1b). The plants were grown in baskets filled with stabilizing medium of rockwool. The baskets were placed in the system such that the root zone was hanging free in a dark chamber. A spray nozzle installed in the dark chamber provided the root zone with water and nutrients. The conditions of the system were highly controllable, enabling the company to establish near to optimal growth conditions. Sweet basil was grown with a constant temperature of 25 °C and a humidity between 55-60 %. The plants were only given the nutrient ‘Blomstra’ treatment as described above for the hydroponic cultivation system, and only the light treatment of L3 (i.e. no colour filters). One high-pressure pump controlled the distribution of water and nutrients from a water reservoir for one unit of three shelfs compare to Figure 2 in this paper (Sör, 2017). Harvest was done at the same time for the sweet basil grown in both the aeroponic as in the hydroponic system. The time length of cultivation differed between in the two cropping systems, but the plants of the both systems were close to the same growth stages when harvested.

2.4 Geoponic basil – Purchased from the supermarket

Sweet basil grown in the three systems hydroponics, aeroponics and geoponics were compared to distinguish any qualitative differences due to the choice of system. It should be noted that there was no information on how the plants from the geoponic system had been produced. The plants from the geoponic system were an unknown basil variety bought at the supermarket “Willy´s”. Both the light and nutrient treatments were unknown. Comparing the sweet basil among the systems only showed the general nutrient uptake and biosynthesis of EO in plants bought at the Swedish supermarkets of today. To make the comparison as fair as possible, only plants with the conditions of 'L3+B'were used from the hydroponic production since those represent the same conditions in terms of light and nutrient supply used in the production in the aeroponic system.

2.5 Data collection

When the sweet basil plants had been grown for four weeks in the hydroponic and aeroponic system, the plants were evaluated on growth, morphology, the contents of nutrients and EO.

2.5.1 Non-destructive analysis – growth and morphology

The sweet basil plants grown in the hydroponic system were analysed non-destructively at the day of harvest. Physical measurements of height and leaf size were carried out using a folding ruler. Plant height was measured from the pot to the tip of the top shoot. The length of the third, fully developed leaf from above was also measured. The SPAD values (SPAD-502, Konica Minolta Sensing Inc., Japan) of the same leaves were recorded on the mean value of three measuring points determining the leaf chlorophyll content (Dongliang *et al.* 2015).

2.5.2 Destructive analysis – chemical analysis of plant material

After harvest, the plant samples were dried in paper bags at 40 ºC for 63 h followed by determination of plant biomass. Half of the plants from each treatment was then used for nutrient analysis and the other half for EO analysis.

2.5.3 Nutrient content

Agri Lab, a commercial laboratory, measured the nutrient content of the plants. Thus, N concentrations were analysed on a LECO CN-2000 analyser using a standard method (SS-ISO 13878). The contents of P, K, Ca, Mg, S and Na were extracted using 32.5 % nitric acid on a heat block and concentrations were determined using ICP-AES technique (Spectro Blue FMS 26, Spectro Analytical Instruments, Kleve, Germany) by applying internal standardization protocols.

2.5.4 Qualitative traits of essential oils

The taste of the basil leaves is related to the EO content, which was assessed in terms of a quantitative EO evaluation here conducted by extraction followed by gas chromatography-mass spectrometry (GCMS) in the facilities of the SLU Ecology Centre. The extraction was done by mixing and pulverizing the sweet basil samples with an internal standard of the solvents n-hexane and n-decane. The extraction flasks were incubated in a stirring water bath at 55 ºC for 2.5 h. Using a Büchner funnel the samples were filtrated in a vacuum and subsequently analysed using GCMS.

2.6 Statistical analysis

For the statistical analysis the program R and RStudio were used as analytic tools (RStudio Team 2015). Analysis of variance (ANOVA) was used to assess the effects of the two main factors light and nutrients and their interactions on the morphological, growth and nutrient traits using Pearson interaction coefficient. For the trade-off effects, correlation test was used. Graphs, linear and quadratic regressions were created in Microsoft Excel.

3 Results

3.1 Pre-study of light settings

The properties of the three light treatments were examined on the PAR and R:FR. Both PAR and R:FR increased with the colour treatments green < yellow < control (Table 2).

Table 2: The light characters of the three light treatments of the experiment in photosynthetic active radiation (PAR) and the ration of red and far red light (R:FR).

	Green	**Yellow**	**Control**
PAR [µmol m^{-2} s^{-1}]	20	49	68
R:FR	37	60	70

3.2 Hydroponic system

The study of the hydroponic system focused on the effects of light and nutrients and their interactions (Table 3).

3.2.1 Biomass growth and morphology

Biomass differed significantly between the light regimes, with increasing values from green < yellow < control for both nutrient regimes (Figure 3a, Table 3). In addition, biomass increased consistently with increasing PAR supplied by the various light regimes (Figure 3b). Light further significantly influenced height, leaf size and SPAD, and was increasing with PAR like biomass (Figure 3a, 3b). Nutrient regime and the interaction of the two factors, light and nutrient, had no effect on the traits growth and morphology (Table 3).

3.2.2 Nutrient content and nitrogen-to-phosphorus ratio

The uptake of all nutrients increased with increasing PAR of the light treatments (green < yellow < control) in both nutrient regimes (Table 3). Nutrient treatment ('Blomstra' or 'Hydro A+B') significantly affected the uptake of N, P, Ca and Mg (Table 3, Figure 3c). Increasing PAR had a more pronounced effect on the nutrient uptake in the 'Blomstra' treatment compared to the 'Hydro' treatment (interaction effect in Table 3, Figure 3c for P). The N:P-ratio was unaffected by the light treatment but differed between the nutrient treatments only when grown in 'Blomstra' (interaction effect in Table 3, Figure 3d). No significant correlation was determined between biomass and N:P-ratio (Pearson r = -0.34, p = 0.16), indicating that R_G was not affected by the N:P ratio. When analysed separately for the two nutrient treatments, N:P ratio and biomass were negatively correlated in the 'Blomstra' treatment (Pearson r = -0.75, p = 0.019), while no significant correlation between these traits was found in the treatment of 'Hydro A+B' (Pearson r = 0.28, p = 0.47).

*Table 3:Results from two-way-ANOVA showing the effects of the light and nutrient regimes and their interactions on the response variables total biomass, total plant height, leaf size, chlorophyll content (SPAD) and the uptake (total pool) of various nutrients and essential oils after four weeks of growth in the hydroponic system. *** $p \leq 0.001$, ** $p \leq 0.01$, * $p \leq 0.05$ and n.s.=not significant.*

	Response Variable	**Light**	**Nutrient**	**Nutrient x Light**
Growth & morphology	*Biomass*	***	n.s.	n.s.
	Height	***	n.s.	n.s.
	Leaf size	**	n.s.	n.s.
	SPAD	***	n.s.	n.s.
Nutrient	*N:P-ratio*	n.s.	***	*
	N	***	*	*
	P	***	***	***
	K	***	n.s.	*
	Ca	***	***	n.s.
	Mg	***	*	n.s.
	Na	**	n.s.	n.s.
	S	***	n.s.	n.s.
Essential oils	*Eucalyptol*	**	*	n.s.
	Linalool	*	n.s.	n.s.
	Estragole	n.s.	n.s.	n.s.
	Eugenol	*	*	n.s.
	Methyl eugenol	n.s.	n.s.	n.s.

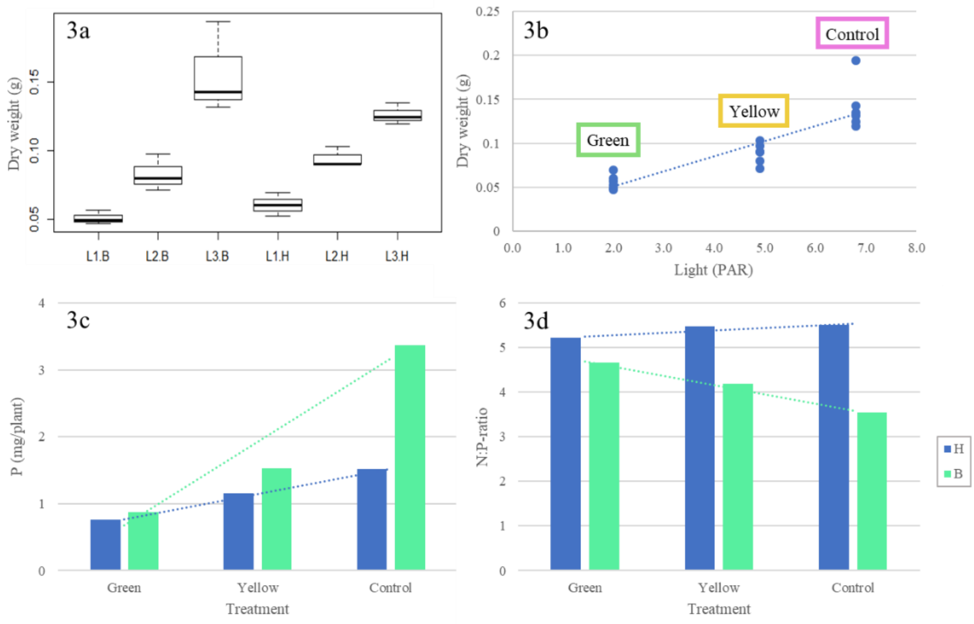

Figure 3: Biomass of sweet basil plants grown hydroponically for four weeks under two nutrient and three light regimes (exempli gratia Fig. 2). a) Box plot showing the mean value and 25 %-quartiles for biomass observed in the six treatments. L1=green, L2=yellow, L3=control, B=’Blomstra’, H=’Hydro A+B’ b) Linear regression (n=18 , r^2=0.77, $p < 0.001$)between the mean total plant biomass of sweet basil and the light (PAR) irradiance achieved across three light regimes. c) Linear regression between mean total P-content for H=‘Hydro A+B’ and B=‘Blomstra’. d) Linear regression between mean total N:P-ratio of the nutrient solutions for H=‘Hydro A+B’ and B=‘Blomstra’.

3.2.3 Essential oils

The EO were statistically analysed in the same way as nutrient uptake, with ANOVA. Light and nutrient treatment influenced the biosynthesis of eucalyptol and eugenol, whereas light alone had an impact on the synthesis of linalool (Table 3). No interaction effects of light and nutrient were found for any of the EO (Table 3). In both nutrient solutions, the concentrations of the same three EO increased with increasing PAR (green < yellow < control) (Figure 4a-c). Methyl eugenol allocation was not influenced by neither light nor nutrient solution (Table 3). The allocation of methyl eugenol did not follow the same trend of increase with increasing PAR as the other EO (Figure 4d). It should be noted that no estragole was detected in any of the plants grown in the hydroponic system and was therefore not further analysed (Table 3).

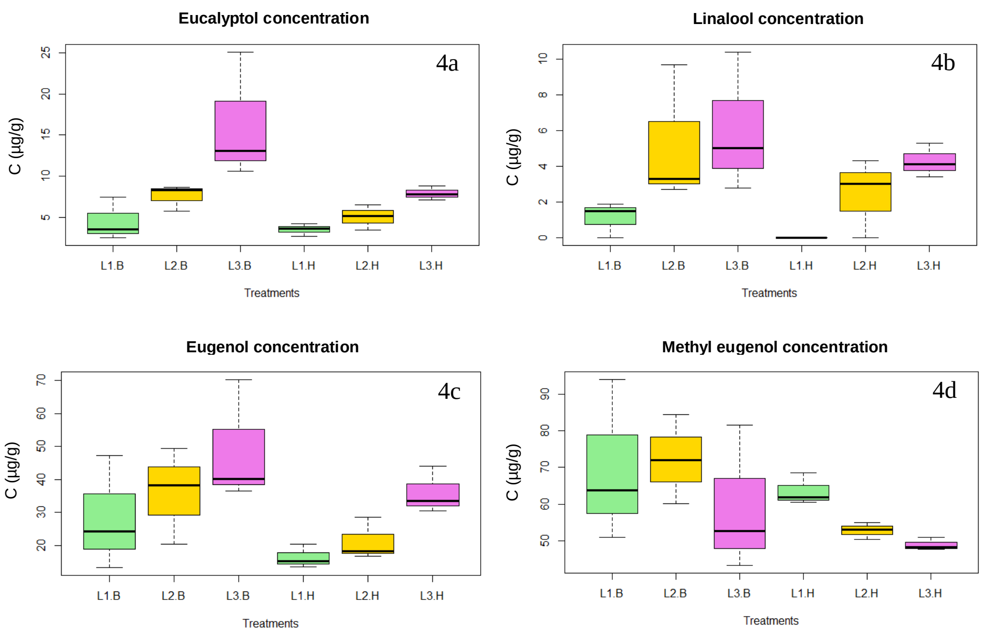

Figure 4: The allocation of essential oils in the hydroponic system of sweet basil, with the treatments of green (L1), yellow (L2) and control (L3) light combined with the nutrient treatments of `Blomstra` (B) or `Hydro A+B` (H). The treatments are presented in the x-axis, while the y-axis presents the concentration (C) of essential oil (µg/g). (a.) eucalyptol, (b) linalool, (c) eugenol, (d) methyl eugenol.

3.2.4 Trade-off effects

In the next step, the trade-off effect of the response variables was investigated using correlation analysis. In the combined data set, including the data from both nutrient treatments (‘Blomstra’ and ‘Hydro A+B’), only very few marginally significant correlations between biomass and morphological traits were detected. Separate correlation analyses for ‘Blomstra’ and ‘Hydro A+B’ revealed stronger correlations between EO and traits of growth and morphology (biomass, height and SPAD) with the nutrient regime of ‘Hydro A+B’ compared to the ‘Blomstra’ treatment (Table 4, Figure 5a and 5c). It should be highlighted that the methyl eugenol concentration decreased with increasing biomass, height and SPAD when the plants were grown in ‘Hydro A+B’ (Table 4, Figure 5a and 5c). ‘Blomstra’, on the other hand, generated fewer significant correlation effects, with only eucalyptol being positively correlated with biomass, height and leaf size (Table 4, Figure 5b and 5d).

*Table 4: Results from the correlation analysis of morphologic traits and essential oils in the plants grown with nutrient solution 'Blomstra' (B) and 'Hydro A+B' (H). The R-value is documented together with the significance levels, with *** $p \leq 0.001$, ** $p \leq 0.01$, * $p \leq 0.05$ and n.s. = not significant.*

	Eucalyptol		**Linalool**		**Eugenol**		**Methyl eugenol**	
	H	B	H	B	H	B	H	B
Biomass	0.918**	0.719*	0.759*	n.s.	0.940**	n.s.	-0.34*	n.s.
Height	0.796*	0.743*	0.709*	n.s.	0.735*	n.s.	-0.86**	n.s.
Leaf size	0.692*	0.696*	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
SPAD	0.892**	n.s.	0.781*	n.s.	0.874**	n.s.	-0.77*	n.s.

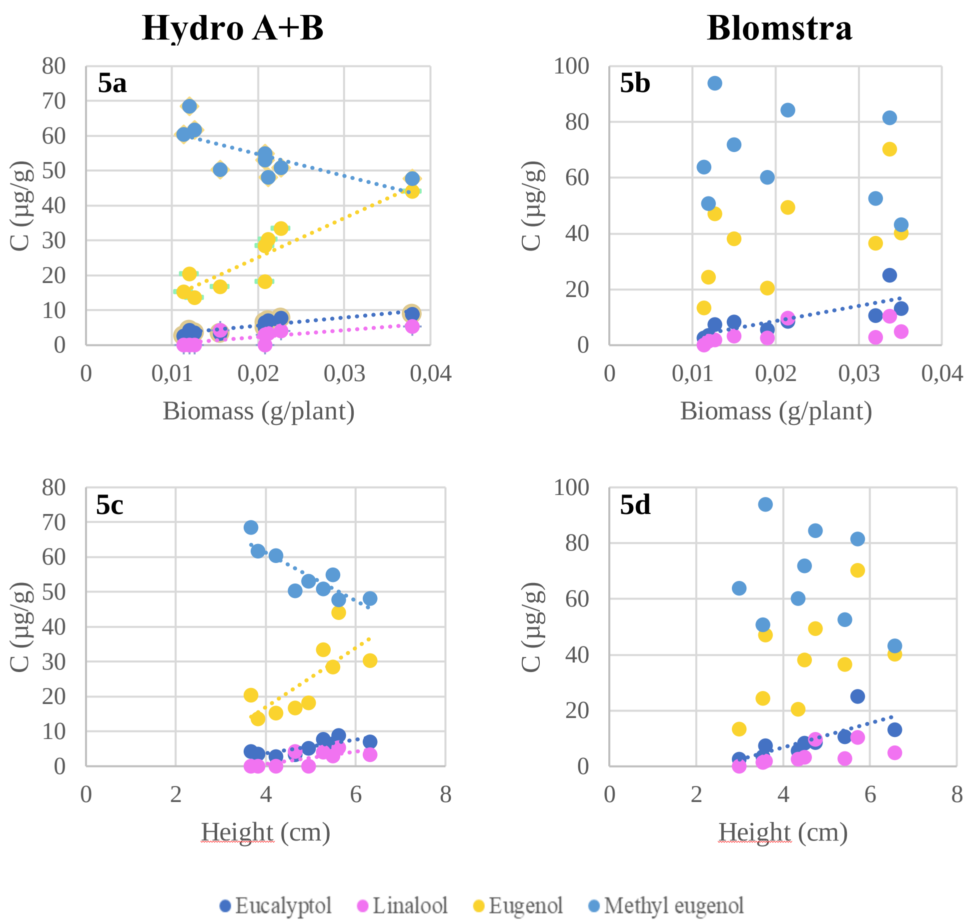

Figure 5: Linear regressions of (a) Biomass vs. EO concentration (C) of sweet basil when grown with the nutrient treatment 'Hydro A+B'. (b) Biomass vs. EO concentration (C) of sweet basil when grown with the nutrient treatment 'Blomstra'. (c) Height vs. EO (C) concentration of sweet basil when grown with the nutrient treatment 'Hydro A+B'. (d) Height vs. EO concentration (C) of sweet basil when grown with the nutrient treatment 'Blomstra'.

A regression analysis using only the data from the plants grown in ’Hydro A+B’ showed decreasing concentrations of methyl eugenol with increasing plant height (Figure 6a), whereas eucalyptol concentrations increased with height (Figure 6b).

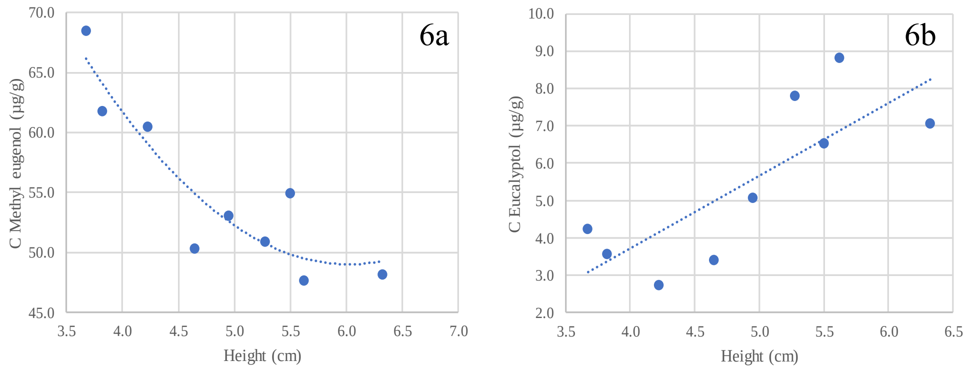

Figure 6: Regressions of essential oil concentrations vs. plant height for sweet basil plants grown with the nutrient solution 'Hydro A+B'. (a) Quadratic regression for the concentration of methyl eugenol vs. height ($y = 3.133\,x^2 - 37.69\,x + 162.3$, $r^2 = 0.84$, $p = 0.004$). (b)Linear regression for the concentration of eucalyptol vs. Height ($y = 1.951\,x - 4.084$, $r^2 = 0.63$, $p = 0.010$).

3.3 Comparing hydroponics, aeroponics and geoponics

The nutrient content differed significantly between the plants grown in the aeroponic system and the hydroponic system (Table 5, Figure 7). Biomass allocation differed amongst the systems and increased from aeroponic<hydroponic<geoponics (Table 5). Basil grown in the hydroponic system had the highest uptake of N, P and K (Table 5, Figure7).

Estragole was not detected in the hydroponic system and only small amounts were found in the plants grown in the geoponic system. In the aeroponic system, the plant concentrations of estragole were among the highest concentrations detected alongside the concentrations of methyl eugenol found in basil grown in the aeroponic system (Table 5, Figure 7).

*Table 5: Comparison between basil plants grown in hydroponics, aeroponic and geoponics with regard to biomass (g/plant), nutrient uptake (g/kg sample) and essential oils (µg/g). The mean values of each system and response variable is presented alongside the results of ANOVA. The plants of the aeroponic and hydroponic systems had been grown under the light treatments of 'control' and the nutrient treatment of 'Blomstra'. *** $p \leq 0.001$, ** $p \leq 0.01$, * $p \leq 0.05$ and n.s.= not significant.*

Response variable	Hydroponics	Aeroponics	Geoponics	p-value
Biomass	0.034	0.025	0.082	***
N-tot	76.8	38.3	37.9	***
P	22.1	9.1	12.1	**
K	71.8	52.1	49.6	***
Mg	4.7	8.3	3.9	***
Na	1.7	3.2	1.5	*
Ca	15.1	22.4	25.5	**
S	4.0	3.1	3.9	**
N:P	3.6	4.3	3.2	n.s.
Eucalyptol	16.3	7.7	6.1	n.s.
Linalool	6.1	4.1	11.5	*
Estragole	0.0	117.1	0.5	***
Eugenol	49.0	26.3	4.1	*
Methyl eugenol	59.2	117.6	51.7	*

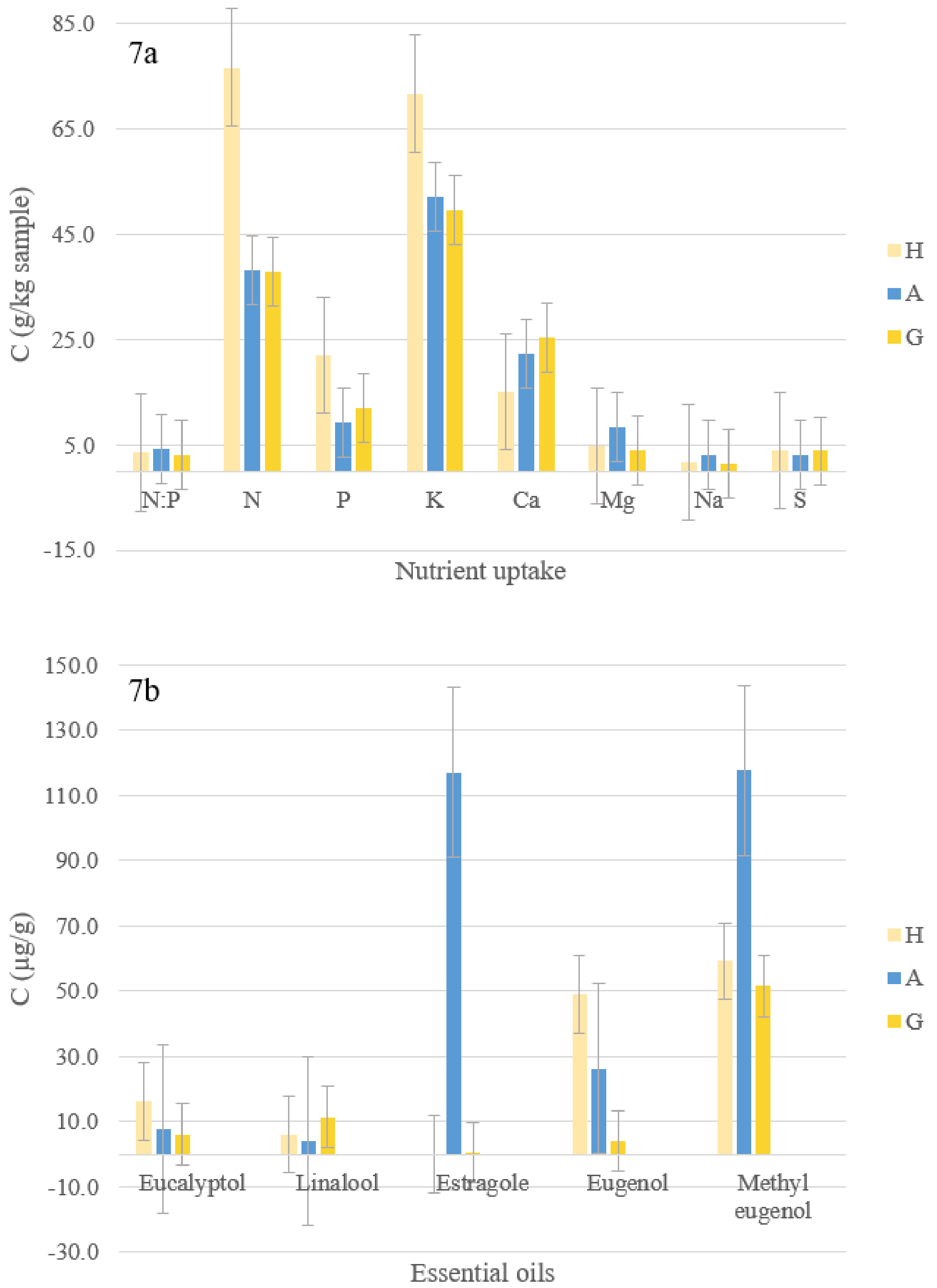

Figure 7: (a) Nutrient contents of basil plants grown in hydroponic (H), aeroponic (A) and geoponic (G) systems. The mean values of N:P-ratio, N, P, K, Ca, Mg Na and S are shown. (b) Mean values of essential oils of the cropping systems hydroponics (H), aeroponics (A) and geoponics (G).

4 Discussion

I would like to start with highlighting the most interesting results. It was rather surprising that the light regime over all had greater effect on the studied traits compared to nutrient regime (Table 3). The trade-off results surprised since nutrient ratios of 'Hydro A+B' showed stronger correlation to biomass and height than 'Blomstra' (Table 4, Figure 5-6). Thus, the composition of the nutrient solution, i.e., 'Blomstra' or 'Hydro A+B', apparently affects the relationship between biomass growth and the concentration of EO. The total lack of estragole came as a surprise among the sweet basil grown in the hydroponic system. Even more unexpected was the finding of high concentration of estragole alongside methyl eugenol in the sweet basil grown in the aeroponic system (Table 5, Figure 7b). These results and more will be discussed in this section.

Before diving into the results, some comments should be said about the experimental design and execution. One could argue that the experiment has weaknesses in the comparison between the different cropping systems. The sweet basil was not grown simultaneously by the same person or at the same location. The plants varied in developmental stages when analysed in the study. Especially the sweet basil grown in the geoponic system had reached later developmental stages, which makes the herbs difficult to compare. Ways of monitoring the cropping systems differed (are unknown for the geoponic system), which can have significant effect on the crops. Even though the monitoring of the cultivation could be improved in further studies, the analysis and comparison between the traits did not lack in precision or accuracy. With that being said, I will move on to the further discussion of results.

4.1 Hydroponic system

Compared to the nutrient treatments ('Blomstra' and 'Hydro A+B'), the light treatments in general had stronger influences on biomass, morphological and physiological traits, uptake of all nutrients uptake and three out of five essential oils (Table 3). The higher the PAR (Table 2), the higher were the allocation of biomass, height, leaf size and SPAD, supporting the hypothesis (*H2*) of increasing R_G with increasing PAR (Figure 3a & 3b).

The nutrient composition (i.e., 'Blomstra' or 'Hydro A+B') did not have any impact on biomass or the other morphological traits. Among the treatments in the hydroponic system, L3+B generated the highest biomass growth (Figure 3a), the highest P value (Figure 3c) and the lowest N:P-ratio (Figure 3d). However, the N:P-ratio was uncorrelated to the R_G. Plants treated with the nutrient solution 'Blomstra' did however show correlation of N:P-ratio and biomass, indicating an effect on the R_G. The nutrient solution ´Hydro A+B' did not show any correlation. I therefore found no support for the hypothesis predicting a higher R_G-performance for the plants grown with 'Hydro A+B' (*H4*).

The cation exchange capacity (CEC) of the growth medium rockwool apparently was not limiting the nutrient supply of the root system, since sweet basil grown with 'Blomstra' showed results of increasing biomass in the treatment of L3+B compared to L3+H (Figure 3a). The different outcomes due to nutrient treatment can be linked back to the nutrient ratios of the nutrient solutions. Plants grown with the nutrient solution 'Blomstra' showed nutrient ratios that were closest to the optimum nutrient ratios of herbaceous plants according to Knecht and Göransson (2004) (Table 1). This is interesting, because even though nutrients supplied by 'Hydro A+B' should have been available in greater concentrations compared to 'Blomstra', the plant uptake of nutrients was not greater (Table 3, Figure 3c, 3d). Knecht and Göransson (2004) argued that any nutrient can be taken up in excess of requirement for growth, but the plant may downregulate the uptake to avoid toxic values. Plants can downregulate the uptake of N, P and K, but are less able to downregulate Mg and are barely capable of downregulating the uptake of Ca (Knecht and Göransson, 2004). Since both Mg and Ca are available in high concentrations in 'Hydro A+B', the ratios may have reached close to toxic levels and limited the growth of basil (Table 1). Another difference between the nutrient solutions is the presents of S in 'Blomstra', but not in 'Hydro A+B' (Table 1). Sulfur is not specifically recommended by Knecht and Göransson (2004) but has been proposed to be growth-limiting for plants in some cases (Dong *et al*. 2017). According to Liebig's law of the minimum, the scarcest nutrient resource will limit the growth and development of the plant. In this case, S could have been a limiting factor in the 'Hydro A+B' treatment of my study, limiting the growth and development of sweet basil.

In contrast to Carvalho *et al*. (2016), I found no support for greater enrichment of EO in plants undergoing the light treatment of green and yellow light (*H1*) in my study (Figure 4). Possible reasons for the discrepancy in results could be the different timing of plant harvests in the two studies. Carvalho *et al*. (2016) found the optimal EO enrichment to be at week 4 out of 6 weeks, whereas the harvest in my study was done later. Further, in the study by Carvalho *et al.* (2016) a different variety of sweet basil was used than in my study. The different varieties may have different optimal growth stages for optimal enrichment of EO. According to Miele *et al*. (2001), also studying the variety Genovese Gigante, the optimal time of harvest for optimal enrichment of EO is right before flowering, which the sweet basil did not reach in my experiment. The chosen time of harvest for my experiment was according to Optima Planta's regular time of harvest in the aeroponic system and for commercial purposes. There could possibly be a time difference in the plant development between the two systems, where the development of sweet basil grown in the hydroponic system is delayed and will not have allocated the same concentrations of EO as sweet basil grown in the aeroponic system. The exact developmental stage of the sweet basil variety Genovese Gigante was not determined before harvest in this study but could be an important addition for further studies. A recommendation of further studies comparing the R_G of sweet basil grown under the same period, conditions and monitoring in the various cropping systems of hydroponics, aeroponics and geoponics.

Another explanation for the EO allocation being lower with the treatment of green and yellow light could be the lower PAR (Table 2). The shortcoming of PAR in green and yellow light limit the R_G of sweet basil grown under these light conditions (Figure 3a-b), meaning that these plants cannot allocate as high concentrations of EO as the plants grown under the light conditions of control (Figure 4). Different light strategies could be used to improve the allocation of both EO and R_G. For further studies, one option could be to use the coloured light of green/yellow during the last time period before harvest. The plants will thereby be able to optimize their R_G first with the light of control followed by the optimization of EO using additional light of green/yellow before harvest. It could be better to use a combination of wavelengths to rather than coloured plastic films to generate various colour settings (Carvalho *et al*., 2016).

Analysis of the possible trade-offs (*H3*) between optimizing for high R_G and quality (taste, here by means of EO concentrations) indicated a possible trade-off when evaluating the plants from the two nutrient treatments separately. In the plants exposed to the nutrient treatment ‘Hydro A+B’, strong correlations were found between the growth and morphology traits, biomass, height and SPAD, and all the EO (Table 4). Thus, eucalyptol, linalool and eugenol concentrations all increased with biomass and height within the treatment of ‘Hydro A+B’, while the concentrations of methyl eugenol decreased. Consequently, methyl eugenol was the only EO not following the trend of increased concentrations as PAR increased (Figure 4d). I consider this a very interesting discovery, especially since the plants grown in ‘Blomstra’ generated higher concentrations in the other examined EO (Table 4a-c). Miele *et al*. (2001) consolidate the high concentration of methyl eugenol to be common in early stages of development within sweet basil. The concentration decreased with growth in terms of plant height in later developmental stages (*H6*). When grown with the treatment of nutrient solution ‘Hydro A+B’, the biomass, height and SPAD showed a negative correlation, supporting that methyl eugenol decreases with increasing R_G (Table 4, Figure 6a). Since methyl eugenol can be toxic in high concentrations (Miele *et al*., 2001), the timing of harvest and the appropriate developmental stage of the plant is crucial. As earlier mentioned, the nutrient ratio of Mg and Ca are poorly downregulated by herbaceous plants to prevent the plant from taking up toxic amounts (Knecht and Göransson, 2004). The high nutrient concentrations supplied to plants by ‘Hydro A+B’ could have been negatively affecting the RG, which in turn could have caused negative effects on the allocation of essential oils. This could mean that there is a close link between R_G and EO (Table 4, Figure 5).

4.2 Comparison between culture systems: Hydroponics, aeroponics and geoponics

Plants from the aeroponic system showed high concentrations of both estragole and methyl eugenol compared to the other systems. As Miele *et al*. (2001) concluded, methyl eugenol is expected to appear in higher concentration if the plants are short (H6). Even though the height of the plants grown in the aeroponic system were not measured, one can assume that the plants were shorter due to the lower biomass (Table 5). Methyl eugenol is present in many vegetables and herbs, but human consumption should be avoided in higher concentrations as it can work toxic (Miele *et al.*, 2001). The high concentration should be possible to avoid by harvesting the sweet basil at a time of greater height since the concentration of methyl eugenol decreases with taller plants (Miele *et al*., 2001). An extended vegetation period should enable the plant the time to grow taller.

There was a difference in nutrient uptake between the three systems (Table 5, Figure 7a). The difference in nutrient uptake could be explained by the plants from the hydroponic and aeroponic system being younger than the plants from the geoponic system. Even though, that does not explain why the nutrient uptake of the plants grown in the aeroponic system was lower than of the basil grown in the hydroponic system. By looking at the nutrient uptake of the plants grown in the aeroponic system, the low uptake of P is notable (Table 5). The possibly limited supply of P could therefore be the reason for the limited growth of the plants grown in the aeroponic system. It could be that the aeroponic system requires a higher dose of P, which is less mobile than e.g. nitrogen, for the nutrient to fully reach the plant roots (*H5*). When planning the study, I expected rockwool to retain some of the supplied P, due to its high CEC, which could limit P delivery to the roots. But as that was apparently not the case in the hydroponic system, it is unlikely to be the case in the aeroponic system. There could be another component in the construction of the aeroponic system with unknown CEC, but that is rather unlikely. Another reason for the limited P uptake in the aeroponic system is the possibility that the sweet basil is in competition for the P by another organism. This theory is rather likely as both the hydroponic and the aeroponic system are easily colonised by bacteria, fungi and algae as the water in the systems are used continuously throughout the cultivation of sweet basil (Zinnen, 1988). The 'dark chamber' of the aeroponic system was transparent which can have led to other photosynthetic organisms to colonize and use up some of the P available in the nutrient solution.

One cannot overlook the high concentration of estragole found in sweet basil grown in the aeroponic system (Figure 7b). Especially considering the same essential oil was barely found in the sweet basil grown in the hydroponic and geoponic systems (Figure 7b). To understand why the levels of estragole are standing out in the aeroponic system, one must understand the properties of estragole. Looking closer at the characteristics of the phenylpropene estragole, it has an antimicrobial effect making it suitable for preservative use in agriculture defeating fungi as well as gram-positive bacteria (Andrade *et al*., 2015, Kocić-Tanackov *et al*., 2001). The high concentrations could be explained as a defence mechanism of the plant. My theory is that bacteria and/or algae have colonized in the water tank and are spreading fast as the water in the aeroponic system recirculates. The colonization has been made possible by the transparent "dark chambers" enabling photosynthesis of algae and/or photosynthesising bacteria. The theory of unwanted colonizers connects back to the earlier mentioned theory of the competition of P uptake between the plants and unwanted organisms. If colonization could be confirmed, estragole levels could possibly come to practical use among conventional sweet basil growers as an indicator of pollutant in the cultivation environment. Arrangements could be made faster to diminish outbreak of diseases and algae expansion. Further studies need to be made to confirm if the estragole can be put to use as an indicator.

Due to the likely issue of contamination, the comparison between the three cultivation systems is difficult. Both the nutrient uptake and the concentration of EO has most likely been influenced by the contaminated environment of cultivation in the aeroponic system, and the corresponding results must therefore be interpreted with care.

4.3 Future of soilless cultivation in Sweden

Looking at what the future may hold for hydroponics one has to look at vertical farming in the present time. Vertical farming has been on the rise the past years with large investors such as IKEA and Google Ventures (Kobayashi-Solomon, 2019). The amount of large-scale commercial companies are increasing worldwide and Sweden is no exception with the conventional farmers; Grönska, Ljusgårda, Björkekulla, Bonbio, Urban Oasis and SweGreen, to name a few. Looking at the ongoing entrepreneur climate, I believe more farms will be built in Sweden in the future looking at how the industry is developing.

Light regime has proven important in this study since it has a large impact on the plant development and nutrient uptake. The Swedish company Heliospectra has drawn the same conclusions and is today developing versatile LED lighting solutions for indoor farming. The challenge with hydroponics is the extensive energy consumption mainly due to the power needed for the LED lights (Kobayashi-Solomon, 2019). For vertical farming to become sustainable and profitable, the energy consumption needs to decrease.

5 Conclusions

Light regime played a large role in the aspects of growth and morphology as well as nutrient uptake. The R_G did increase with increasing PAR (*H2*), which increased with the light regimes of green < yellow < control. The light regime also influenced the concentration of essential oils (EO) eucalyptol, linalool and eugenol. However, the study showed no support for greater enrichment of EO in plants undergoing the light treatment of green and yellow light (*H1*).

Regarding the expectation of a trade-off effect when optimizing for R_G and EO concentrations (*H3*), there were positive correlations found in the results using the fertilizer 'Hydro A+B'. The composition of chemical elements in the fertilizer do influence the relationship between biomass and EO content, which can be applicable in the practical farming. I also expected plants grown with the nutrient solution of 'Hydro A+B' to perform better in terms of relative growth rate (R_G) due to a lower N:P ratio (*H4*). However, N:P-ratio and biomass did not correlate in the plants grown with 'Hydro A+B', but they correlated when grown with 'Blomstra'. The R_G rather increased with a N:P-ratio close to the recommended ratio of herbaceous plants. As predicted did the methyl eugenol levels decrease with increasing R_G (*H6*), indicating that methyl eugenol is present in higher concentrations during the earlier developmental stages in sweet basil.

Since the aeroponic system was most likely contaminated, the comparison between the cropping systems should be carried out with care (*H5*).

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Appendix 1

Sample-ID	Light	Nutrient	System	Mean	Biomass	Height	Leaf.size	SPAD	N-tot	Ca	K	Mg	Na	P	S	N:P-ratio	Eucalyptol	Linalool	Estragole	Eugenol	Methyl eugenol
				plant/pot	g/plant	cm	cm		mg/plant	mg/plant	mg/plant	mg/plant	mg/plant	mg/plant	mg/plant	mg/mg	µg/g	µg/g	µg/g	µg/g	µg/g
1	Yelow	H		5	0,01561	4,7	3,6	20,4	1,04	0,43	1,12	0,11	0,03	0,20	0,06	5,29	3,4	4,3	0,0	16,8	50,3
2	Yellow	H		4	0,02076	5,0	4,0	20,5	1,38	0,60	1,55	0,15	0,04	0,26	0,09	5,30	5,1	0,0	0,0	18,3	53,1
3	Control	B	H	4	0,03211	5,4	3,8	26,3	2,43	0,51	2,29	0,16	0,07	0,84	0,12	2,88	10,6	2,8	0,0	36,5	52,6
4	Control	B	H	4	0,03376	5,7	4,0	25,0	2,63	0,50	2,50	0,15	0,05	0,74	0,14	3,54	25,1	10,4	0,0	70,3	81,6
5	Control	H		6	0,02112	6,3	4,2	24,0	1,45	0,59	1,48	0,14	0,04	0,24	0,09	5,97	7,1	3,4	0,0	30,4	48,2
6	Control	H		5	0,02261	5,3	3,5	22,4	1,44	0,55	1,70	0,13	0,03	0,28	0,09	5,12	7,8	4,1	0,0	33,4	50,9
7	Yellow	B		4	0,02153	4,8	3,9	23,3	1,66	0,39	1,44	0,13	0,05	0,40	0,09	4,13	8,6	9,7	0,0	49,4	84,4
8	Green	H		5	0,01137	4,2	3,2	19,2	0,74	0,32	0,78	0,09	0,03	0,15	0,05	4,92	2,7	0,0	0,0	15,3	60,5
9	Yellow	B		4	0,01903	4,4	3,3	24,6	1,50	0,30	1,29	0,10	0,04	0,38	0,08	3,97	5,7	2,7	0,0	20,4	60,1
10	Green	B		5	0,01140	3,0	2,3	14,6	0,90	0,20	0,72	0,07	0,03	0,20	0,05	4,60	2,5	0,0	0,0	13,3	63,8
11	Green	H		5	0,01202	3,7	3,5	18,6	0,76	0,32	0,86	0,09	0,03	0,14	0,05	5,41	4,2	0,0	0,0	20,4	68,5
12	Green	B		4	0,01196	3,6	3,3	18,8	0,94	0,25	0,78	0,08	0,03	0,21	0,06	4,53	3,5	1,5	0,0	24,3	50,9
13	Yellow	B		5	0,01506	4,5	3,7	22,3	1,14	0,28	0,99	0,09	0,03	0,26	0,07	4,46	8,3	3,3	0,0	38,2	72,0
14	Yellow	H		5	0,02075	5,5	4,3	23,9	1,39	0,54	1,60	0,13	0,04	0,24	0,08	5,81	6,5	3,0	0,0	28,5	55,0
15	Green	H		5	0,01262	3,8	3,9	20,1	0,83	0,32	0,90	0,09	0,03	0,16	0,06	5,31	3,6	0,0	0,0	13,6	61,8
16	Control	B	H	5	0,03519	6,6	4,3	28,0	2,70	0,52	2,46	0,16	0,05	0,64	0,15	4,23	13,1	5,0	0,0	40,2	43,3
17	Green	B		4	0,01272	3,6	3,3	21,0	1,03	0,26	0,79	0,09	0,04	0,21	0,06	4,83	7,4	1,9	0,0	47,2	94,0
18	Control	H		4	0,03788	5,6	4,7	25,2	2,45	0,91	2,71	0,21	0,06	0,45	0,14	5,43	8,8	5,3	0,0	44,1	47,7
Optima Planta 1			A	5	0,03117				1,27	0,57	1,53	0,22	0,14	0,24	0,10	5,33	7,6	3,7	138,0	14,1	89,5
Optima Planta 2			A	5	0,02251				0,82	0,56	1,17	0,21	0,05	0,23	0,07	3,51	7,5	5,4	134,1	23,9	111,2
Optima Planta 3			A	5	0,02092				0,79	0,51	1,16	0,18	0,06	0,20	0,06	4,03	7,9	3,3	79,1	41,0	152,0
Garant 1			G	27	0,09096				3,25	2,38	4,31	0,36	0,12	1,11	0,36	2,92	6,0	13,8	1,6	4,6	53,7
Garant 2			G	27	0,06898				2,82	1,66	3,57	0,25	0,12	0,79	0,24	3,58	5,6	8,9	0,0	4,0	53,1
Garant 3			G	27	0,08554				3,17	2,25	4,24	0,34	0,14	1,07	0,35	2,96	6,6	11,8	0,0	3,8	48,2

Appendix 1: Raw data used to calculate the statistical analysis. "Sample-ID" names the hydroponic growth chambers (1-18), the aeroponic growth chambers (Optima Planta 1-3) and the geoponic produced cultivars (Garant 1-3). "Light" regimes used for the hydroponic cultivation was yellow, green and control. "Nutrient" regimes of Hydro A+B (H) and Blomstra (B) were used for the hydroponic cultivation. The samples used for the comparison of the systems are seen in the column "System" with the description hydroponic (H), aeroponic (A) and geoponic (G). "Mean" describes amount of plants per pot which is then divided by the dried biomass presented as "Biomass". Further growth and morphological traits where studied of the hydroponically grown cultivars, looking at plant height, "Height", "Leaf size" and chlorophyll content, ("SPAD"). Nutrient content was analysed upon nitrogen (N-tot), calcium (Ca), potassium (K), magnesium (Mg), sodium (Na), phosphorus (P), sulfur (S) and N:P-ratio. The content of the essential oils eucalyptol, linalool, estragole, eugenol and methyl eugenol were confirmed.