D4.2 – Growing Fresh Food Crops in the FEG: Cultivation Recipe

prepared for

WP 4.2 – Plant Cultivation Experiments and Training

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0.1	27-2-2017	E. Meinen, T. Dueck	Initial version
0.2	17-5-2017	E. Meinen, T. Dueck	Including height of plants, detail plug, spacing plants, pruning pepper
0.3	26-6-2017	E. Meinen, T. Dueck	Comments of SAB and EC reviewers processed; except 1 point about the suggestion to make a more detailed description of the facilities and the adaptation of the results to a different cultivation method.
1.0	03-8-2017	E. Meinen, T. Dueck	Minor formatting updates. Final release.

Executive summary

The aim of the EDEN ISS project, described earlier by Zabel et al. (2016), is to design and build a mobile test facility (MTF) in which crops can be cultivated, that will be deployed to the Neumayer III Antarctic station. Vegetable crops will be grown in a closed system and provide the crew with ready-to-eat fresh food. Due to the limited space in the MTF, all crops will be grown in a single growth compartment in the MTF and thus an ‘average climate’ suitable for all different crops was selected. Under these conditions, some crops are expected to grow and produce well, some sub-optimally, but still sufficiently well to produce a satisfactory amount of fresh food.

This report describes the cultivation procedure for several ready-to-eat crops: lettuce, leafy greens, radish, herbs, tomato, cucumber and pepper. The climate, settings of the lamps, nutrient solution, sowing procedure, crop management and harvesting are described. The procedure is based on existing (Dutch) knowledge and on the results of several trials with different light intensities, temperatures, spectral quality and crop management (single or spread harvest) performed in order to assess the requirements for optimal growth and production of each crop. Experiments were performed in two climate chambers in Wageningen in The Netherlands using rock-wool substrate and an ebb and flow system to supply nutrient solution. In the MTF an aeroponic system will be used. The aeroponic system was tested in Wageningen with lettuce Crispy Green Expertise and this worked well, although regular control of the nozzle/spray system was necessary.

The cultivation procedure and production values are presented per crop per m^2. Based on this information a cultivation scheme can be designed for the optimal fresh food production in the MTF at the Neumayer III Antarctic station.

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Acronyms

Acronym	Explanation	Acronym	Explanation
BLSS	Bio-regenerative Life Support Systems	DW	Dry weight
FEG	Future Exploration Greenhouse	FW	Fresh weight
HS	Heliospectra BA	R/FR	Red/far-red ratio
MTF	Mobile Test Facility	PAR	Photosynthetic active range
NDS	Nutrient Delivery System		
WP	Work Package		

1 Introduction

The aim of the EDEN ISS project, described earlier by Zabel et al. (2016), is to design and build a mobile test facility (MTF) for fresh food production, that will be deployed to the Neumayer III Antarctic station. Vegetable crops will be grown in this closed system and provide the crew with ready-to-eat fresh food. The foremost constraint in this facility, next to the extreme outdoor climate, is the limitation placed on the amount of available energy.

Several different crops will be cultivated with their specific requirements for optimal growth and production. Due to the limited space in the MTF, all crops will be grown in the single growth compartment of the MTF and thus an 'average climate' suitable for all different crops should be selected. Under these conditions, some crops are expected to grow and produce well, some sub-optimally, but still sufficiently well to produce a satisfactory amount of fresh food. To find out the best 'average climate' for the crops several experiments were carried out in Wageningen from March 2016 until January 2017 where different light intensities, temperatures, spectral composition of light and crop management procedures were tested. This resulted in cultivation recipes for all crops which are presented in this report. Detailed results of all experiments carried out will be presented in another report.

1.1 Selection of crops

For the selection of crops, physical and physiological aspects and human well-being are the most important factors (Dueck et al., 2016). Quality aspects, such as taste, texture, appearance are related to human well-being. Crops should be 'ready-to-eat', and the harvest-index and production should be high. The methodology includes a framework for the selection process, a list of relevant criteria based on plant characteristics, engineering constraints and human nutrition and psychology. It entails a scoring system to assess and weigh these criteria for each crop, in order to rank the chosen crops. Physical and physiological constraints determine whether or not a crop can be cultivated in space or Antarctica and all other parameters are prioritized according to human quality aspects, yield or production aspects that were ranked according to pre-selected weighing factors. This selection methodology yielded a ranking of crops to be grown in a controlled biological life support system suitable for future space missions and for the Neumayer III Antarctic station. The final ranking of selected crops (Dueck et al., 2016) is presented in Table 1.

Table 1. Final score (arbitrary index) and ranking of selected crops to be cultivated in the FEG.

Crop	Score	Crop	Score
Lettuce	48.8	Spinach	14.6
Cucumber	37.9	Swiss chard	11.9
Dwarf tomato	26.9	Bell pepper	10.8
Chives	26.3	Red mustard	8.0
Tomato	26.3	Coriander	7.9
Strawberry	17.3	Watercress	6.7
Radish	16.9	Basil	2.9
Parsley	14.7		

All crops (except watercress) were tested and several cultivars of lettuce because of the high score.

1.2 Test facilities Wageningen

In Wageningen 2 climate chambers of 6 m^2, each with in total 4 shelves of 285 cm long and 60 cm width were used to cultivate the vegetable crops. They were grown under 3 LED lamps (Heliospectra LX60) per shelf without daylight. The distance between tray and lamp was 90 cm. In picture 1 an overview of the climate chamber is shown.

Picture 1: Climate chamber with 4 shelves and 12 lamps

Plants were grown in rock-wool blocks and placed in open trays of 60 cm x 40 cm x 10 cm. Water and nutrients were supplied with an ebb and flow system, with the nutrient solution tank inside the climate chamber. In the mobile test facility however plants will be cultivated with an aeroponic system. This aeroponic system was tested in Wageningen with lettuce (Crispy Green Expertise) and worked well. However, the system is sensitive for malfunctioning of pumps and blocking of nozzles, so frequent control of the crops and the NDS is important.

Effects of light intensity (200, 300, 450 and 600 µmol m^{-2} s^{-1}), temperature (day/night 21/19, 25/23°C), light spectrum (17% blue and 50% blue) and crop management were investigated. Plants were cultivated at different densities, and the effect of spread harvest (harvesting in time) was tested. By harvesting weekly or twice a week the oldest leaves of a crop, a high plant density can be maintained.

Plant growth, morphology, quality and production were observed and measured. This resulted in cultivation recipes for different groups of crops which are presented in this report.

2 Crops

A large number of crops were tested in the facilities in Wageningen. A number of issues were observed during the experiments like poor germination (strawberry, mint), slow growth (strawberry), early flowering (some cultivars of spinach), plants that became too tall for the available space (indeterminate tomato, cucumber, pepper). In Table 2 a list of selected and tested vegetables is presented with a brief comment on their performance.

Table 2. List of selected and tested vegetables at Wageningen, accompanied by a brief comment on their performance.

EDEN ISS crops/cultivar	Selected	Tested	Comments
Lettuce/Crispy green Expertise	x	x	grew and produced well, good appearance
Lettuce/Batavia Othilie		x	as Crispy green, occasional tip-burn
Lettuce/red Romaine Outredgeous		x	grew and produced well, good appearance
Lettuce/Pulsar		x	remained too small, low production
Lettuce/Iceberg		x	often showed tip burn, did not head well
Cucumber/Quarto	x	x	grew and produced well
Cucumber/Picowell		x	grew and produced well
Determinate tomato:			
Tomato det./F1 2414	x	x	grew and produced well, oval fruits
Tomato det./F1 1202		x	grew and produced well, round fruits
Tomato det./3469B	x	x	grew and produced well, orange fruits, very tasty
Indeterminate tomato:			
Tomato indet./ CandyTom 12.829	x	x	plant is compact
Bell pepper/1601-M	x	x	plant is compact
Bell pepper/Cupid		x	plant is too tall
Strawberry	x	x	raised from seed takes too long, use root stock
Radish/Lennox	x	x	grew and produced well
Radish/Raxe		x	grew and produced well
Rocket/Rucola cultivated	x	x	produced well, much better than other rockets
Rocket/Rucola Sylvetta		x	leaves and plant too small
Rocket/Rucola Selvatica Wild Angel		x	leaves and plant too small
Spinach/Red kitten	x	x	grew well, good appearance, too low production
Spinach/Golden eye		x	poor germination
Swiss chard/Ruby red	x	x	grew and produced well
Red mustard/Frizzy Lizzy	x	x	grew and produced well
Coriander/HI 13475 HEC	x		not tested
Chives/Staro	x	x	healthy appearance, 4x regrowth possible
Chives/Purly		x	grew and produced well
Parsley/Moskrul 2-verta	x	x	grew and produced well

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EDEN ISS crops/cultivar	Se-lected	Test ed	Comments
Parsley/Frise Vert Fonce-Rina		x	healthy appearance, 4x regrowth possible
Water cress	x		not tested
Basil/Dolly	x	x	too few results
Basil/Genovese		x	too few results

During the experiments some cultivars were excluded and new cultivars were included and tested. In Table 3 a list is shown with crops that grew well and were tested under different climate conditions. In Table 4 more crops are listed that also grew well, but were tested under only one climate condition.

Table 3: Crops and cultivars which were tested under different climate conditions.

Crop	**Cultivar**	**Crop height (cm)***	**Company**
Lettuce	Crispy green cv. Expertise	25	RijkZwaan
	Bativia cv. Othilie	25	RijkZwaan
	Red Romaine: Outredgeous	25	Johnny Seeds
Rocket	Rucola cultivated	15 - 20	Growitalian
Red mustard	Frizzy Lizzy	25	HILD zaden (Bayer)
Swiss chard	Ruby Red	25 - 30	Johnny Seeds
Spinach	Red Kitten	15	Johnny Seeds
	Golden Eye	10 - 15	RijkZwaan
Radish	Lennox	15 - 20	Bayer
	Raxe	15 - 20	Bayer
Chives	Staro	25 - 35	Johnny Seeds
	Purly	25 - 35	Johnny Seeds
Parsley	Moskrul 2-Verta RZ	15 - 25	RijkZwaan
	Frise Vert Fonce-Rina	15 - 25	RijkZwaan
Dwarf toma-	F1 2414 (determinate)	40	Vreugdenhil
Compact	CandyTom 12.829 (compact indeterminate)	high	Vreugdenhil
Cucumber	Quarto	high	RijkZwaan
	Picowell	high	RijkZwaan

*Average height measured at 21/19 °C and 300 µmol m^{-2} s^{-1}

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Table 4: Crops and cultivars which were tested under only one set of climate conditions.

Crop	Cultivar	Crop height (cm)*	Company
Lettuce	Field Lettuce cv. Pulsar	10	RijkZwaan
Rocket	Rucola cv. Sylvetta	10	Johnny Seeds
	Rucola Selvatica-Wild Arugula	10	Growitalian
Coriander	HI 13475 HEC	30	HILD zaden (Bayer)
Basil	Dolly	30	Johnny Seeds
	Genovese	30	Johnny Seeds
Dwarf tomato	F1 1202 (determinate)	40	Vreugdenhil
	3469 B; very tasty orange tomato!	40	Vreugdenhil
Pepper	1601-M Mini pepper	➢ 90	Vreugdenhil
	Cupid	high	Johnny Seeds

*Average height measured at 21/19°C and 300 µmol m^{-2} s^{-1}

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3 Growing conditions

3.1 Light

Plants were cultivated with a photoperiod of 17 hours. LED light was provided with Heliospectra lamps (LX60) with 4 channels and peaks at: 450 nm (blue), 660 nm (red), 735 nm (far-red) and 5700K (white). The 'setting' of each channel was regulated on a relative scale (0-1000) and was operated with a computer linked to a router.

Dawn and dusk were simulated by influencing the red/far red ratio (R/FR) of the lamp light. In nature, R/FR is around 1 or 2 but decreases at sunset to 0.7 – 0.8 (Hemming et al, 2004). More far-red at the end of the day influences the plant morphology and physiology. In the light recipe sunset is simulated by using only the white and the far red channel in such a way that R/FR is around 0.75, as in nature. At the start of the day and the end of the day, far-red was still at maximum capacity and white (5700K) was used (set point of '80' in the system used in Wageningen) resulting in 90 µmol m^{-2} s^{-1} with a R/FR ratio of 0.77 (the channels blue and red were off).

The photoperiod was simulated by starting the day with a low light intensity and gradually increasing it. After sowing, the light intensity was set to a maximum of 200 µmol m^{-2} s^{-1}, and then increased to 300 µmol m^{-2} s^{-1} or gradually to 600 µmol m^{-2} s^{-1} when the first leaves had been formed. All crops developed, grew and produced well under 300 µmol m^{-2} s^{-1}. Production of radish and chives was around 40 % higher under 600 µmol $m^{-2}s^{-1}$ compared to 300 µmol m^{-2} s^{-1}.

Table 5: Scheme of light intensity during the day during germination and cultivation

Time	After sowing (µmol m^{-2} s^{-1})	After seedling stage until the end of the cultivation (µmol m^{-2} s^{-1})	After seedling stage until the end of the cultivation (µmol m^{-2} s^{-1})
		All crops except radish, chives	Radish, chives
4:00	Start: sunrise	Start: sunrise	Start: sunrise
4:15	100	150	300
5:00	200	300	600
20:00	100	150	300
20:45	sunset	sunset	sunset
21:00	Lamps off	Lamps off	Lamps off

The far-red channel was always used during the photoperiod at an intensity of 35 µmol m^{-2} s^{-1} (maximum intensity for far-red; setting '1000'). The other 3 channels were set (using the same value for the 3 channels) to the desired light intensity at plant height measured in µmol m^{-2} s^{-1}. After sowing the light intensity was measured just above the seeds; settings were adapted when plants became taller in such a way that the light intensity at the top of the canopy had the desired value. As the plants grew and became taller, the light intensity was altered according to the needs of the crop. These settings resulted in a spectrum in the photosynthetic active range (PAR) of 17% blue (400-500 nm), 12% green (500-600 nm) and 71% red (600-700 nm).

Choosing settings of the 3 channels blue, red and white (same value of settings of these 3 channels) is a 'trial and error' method, aiming to achieve a uniform light intensity distribution at crop height. This is influenced by the number of lamps per m^2, the height of the lamps above the top of the crop and used materials (reflection). The first step is to choose settings for all lamps above one shelf and measure light intensity at different positions at the shelf at crop height. Fine tuning is time consuming but necessary, and results in different settings for all lamps above one shelf:

lamps at the edge of the cultivation area require higher intensities compared to lamps in the middle in order to realize an even light distribution above the crop canopy. The spectrum in the PAR range will remain the same (17% blue, 12% green, 71% red) when the same ratio of settings of the 3 channels blue, red and white will be applied.

3.2 Climate conditions

Plants were cultivated with a photoperiod of 17 hours. CO_2 was supplied at 750 ppm during day and night. The best temperature for the leafy greens and lettuce was 21/19°C during day/night with a light intensity of 300 µmol m^{-2} s^{-1}. Higher light intensities (450 and 600 µmol m^{-2} s^{-1}) resulted in compact plants and worse quality of leaves (harder leaves, less palatable, bitter taste for Swiss chard and rocket). Cultivation at 25/23°C and 300 µmolm^{-2} s^{-1} improved the production of some crops (red mustard) but not of all leafy greens. Some plants became more weak (red mustard, crispy green) and elongated (red mustard). Increasing the light intensity to 600 µmol $m^{-2}s^{-1}$ also resulted in worse quality of the leaves at 25/23°C for lettuce and compact plants. Herbs produced more biomass at 25/23 °C at the first harvest, but regrowth was much better at 21/19°C for parsley.

Fruit vegetables can also be cultivated at 21/19°C like the other crops, but then the first harvest occurs 3 weeks later for tomato and 2 weeks later for cucumber compared to 25/23°C during day/night. Production per week will be probably higher cultivated at 25/23°C since the developmental rate will be higher.

Since all crops are in the same space, 'one' climate should be chosen. In Table 6 the climate conditions are summarized.

Table 6: Climate conditions for the different crops.

Group of crops		Day	Night
Leafy green,	Duration (h)	17	7
Lettuce, herbs,	Light intensity (µmolm^{-2} s^{-1})	200 – 300*	0
Fruit vegetables	Temp (°C)	21	19
	CO_2 (ppm)	750	750
	RH (%)	75	85
Radish, chives	Duration (h)	17	7
	Light intensity (µmolm^{-2} s^{-1})	200 – 600*	0
	Temp (°C)	21	19
	CO_2 (ppm)	750	750
	RH (%)	75	85

*200 µmol m^{-2} s^{-1} after sowing until seedlings stage and after that until the end of the cultivation 300 µmol m^{-2} s^{-1} or 600 µmol m^{-2} s^{-1} for radish and chives.

The climate conditions presented in Table 6 were based on our horticultural experience, advice of growers and several trials in Wageningen. However some experimental testing at Antarctica can be done if desired.

4 Nutrient solution

Plants were cultivated in rock-wool blocks and watered once (small plants) or 2 times a day (ebb and flow system). In general, a nutrient solution was used for leafy greens and fruiting crops in their vegetative stage, while another one should be used for fruit-bearing vegetables. In the MTF 2 nutrient solutions can be supplied; a nutrient solution for leafy greens/vegetative crops (calculated in the fourth column Table 7) and a nutrient solution for fruit bearing crops like tomato, cucumber and pepper (last column Table 7). All tests performed in Wageningen were carried out with one broad-range nutrient solution for all crops (third column Table 6).

In Table 7, the ratio of the concentration of the elements in the nutrient solution is presented. This ratio results in a calculated EC of 1.7 or 1.8 (in Table 'EC calculated'). This nutrient solution is created in concentrated solutions in an A and a B tank.

Table 7: Nutrient solution for all crops (third column) or specific for leafy greens and the vegetative phase of crops (fourth column) and fruit bearing crops (last column)

	Dimension	One nutrient solution for all crops	Leafy greens and vegetative phase of crops	Fruit bearing crops
Macro elements				
NH4	mmol L^{-1}	1	0.9	1.1
K	mmol L^{-1}	6.75	7.6	7.3
Na	mmol L^{-1}			
Ca	mmol L^{-1}	2.625	3.1	2.9
Mg	mmol L^{-1}	1	1.0	1.1
NO3	mmol L^{-1}	11.5	13.2	11.4
Cl	mmol L^{-1}	0.25	0.5	0.5
SO4	mmol L^{-1}	1	0.8	1.6
HCO3	mmol L^{-1}			
H2PO4	mmol L^{-1}	1.25	1.4	1.3
Si	mmol L^{-1}		0.5	
Microelements				
Fe	µmol L^{-1}	20	28	25
Mn	µmol L^{-1}	10	1.4	10
Zn	µmol L^{-1}	5	1.8	4
B	µmol L^{-1}	25	21	21
Cu	µmol L^{-1}	0.75	0.5	0.8
Mo	µmol L^{-1}	0.5	0.3	0.5
EC calculated*	mS cm^{-1}	1.7	1.8	1.7
EC irrigation**	mS cm^{-1}	2.5	2.3	3.5
EC irrigation** - range		2.2 – 2.8	2.0 – 2.8	3.0 – 4.0
pH		5.8	5.8	5.8

*Calculated EC is based on the concentration of the elements in this Table.
**Irrigation EC is the EC needed for the crops.

The EC that should be created for the aeroponic system is higher than the calculated EC and is 2.5 for the broad-range nutrient solution for all crops, 2.3 for the leafy greens and 3.5 for the fruit bearing crops (Table 6). In Table 6, a range of acceptable EC- values is presented. EC should be in the range of 2.0 – 2.8 mS cm^{-1} for leafy greens and 3.0 – 4.0 mS cm^{-1} for fruit vegetables. Generally, a lower EC results in more production and a higher EC results in more taste.

EC and pH are measured twice a week to monitor the stability of the nutrient solution. Target value of pH is 5.8; pH should be in the range 5 – 6.2. Adapt with HNO_3 or $KHCO_3$ (solution of 0.1 mol L^{-1}).

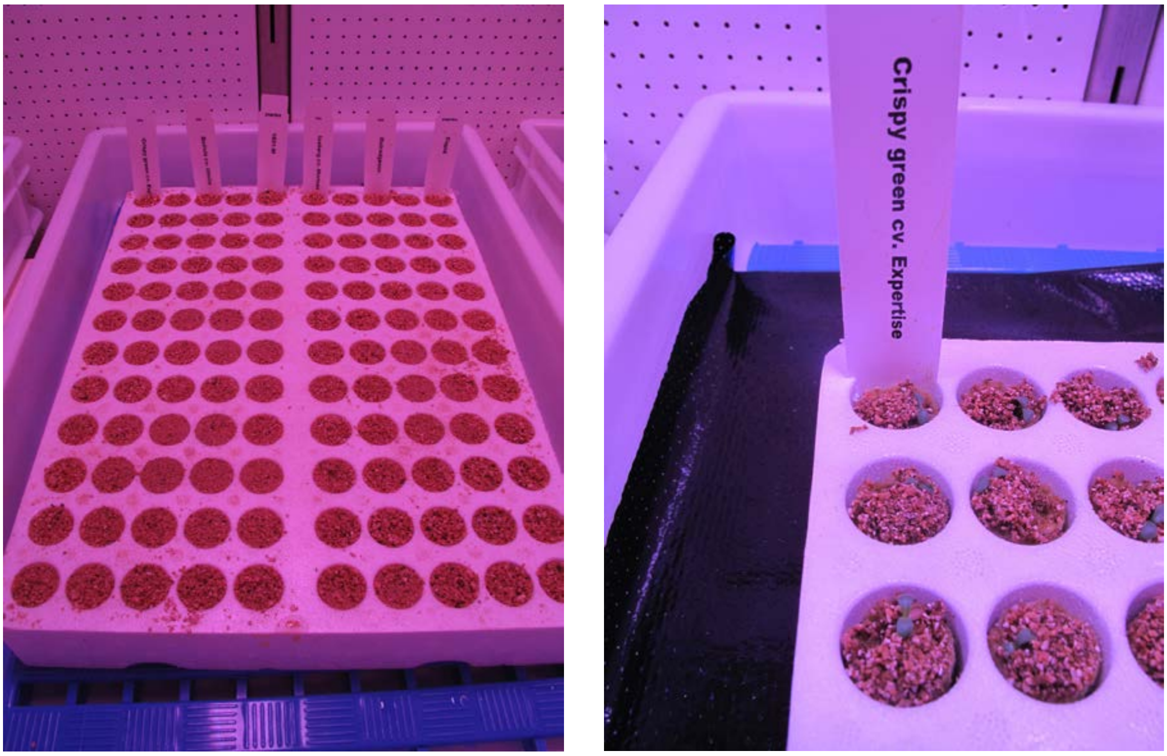
The calculation of the recipes for the nutrient solutions is depended of the type of fertilizers, the concentration and the nutrient delivery system. A tool to calculate the recipe can be found:

http://www.wur.nl/en/Research-Results/Projects-and-programmes/Euphoros-1/Calculation-tools/Nutrient-Solution-Calculator.htm

5 Crop management

5.1 Sowing

- Rock wool plugs (in a tray of styrofoam; plant density 1050 plants m^{-2}) were dipped in nutrient solution until the plugs are completely wet (5 to 10 minutes).
- Sow 1 seed per plug or 3 seeds for chives. It is convenient to put the seeds in a petri dish. Use tweezers for larger seeds or a thin wooden stick for small seeds. Moisten the stick to make the seeds stick and it will be easy to put them in a plug.
- Cover the seeds with vermiculite.
- Make sure the plugs stay moist (check daily).

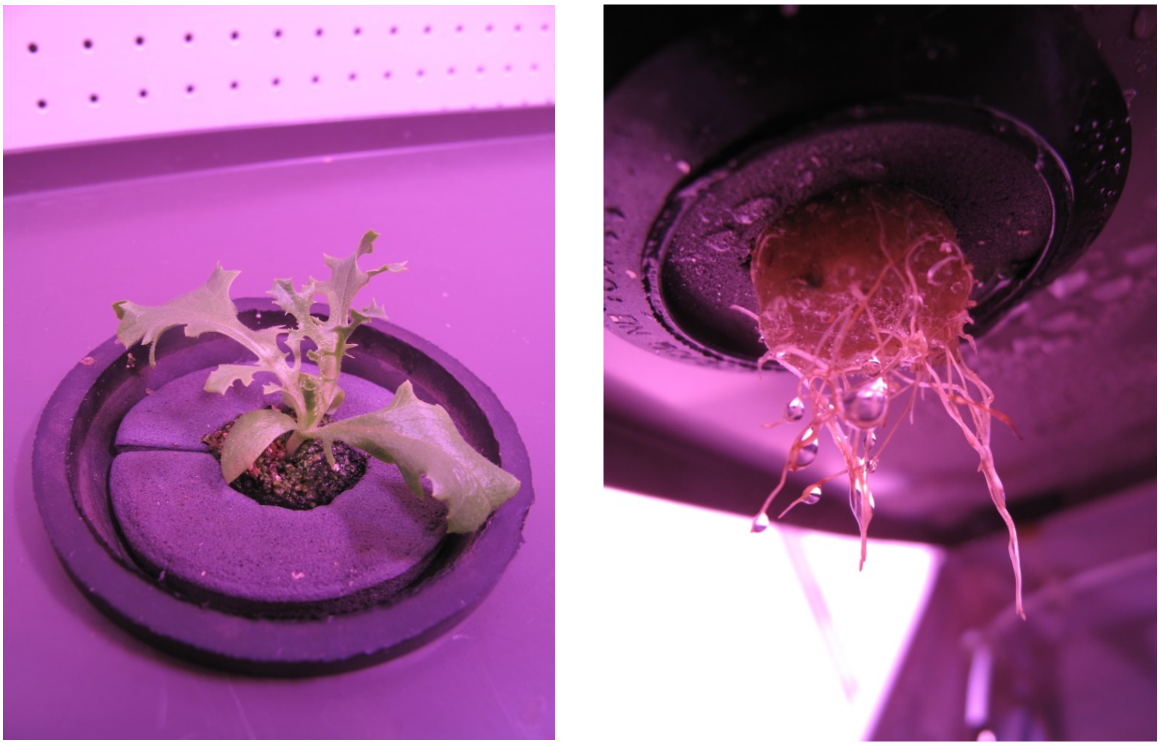


Picture 2: Rock wool plugs with seeds (left) and 5 days after sowing (right)

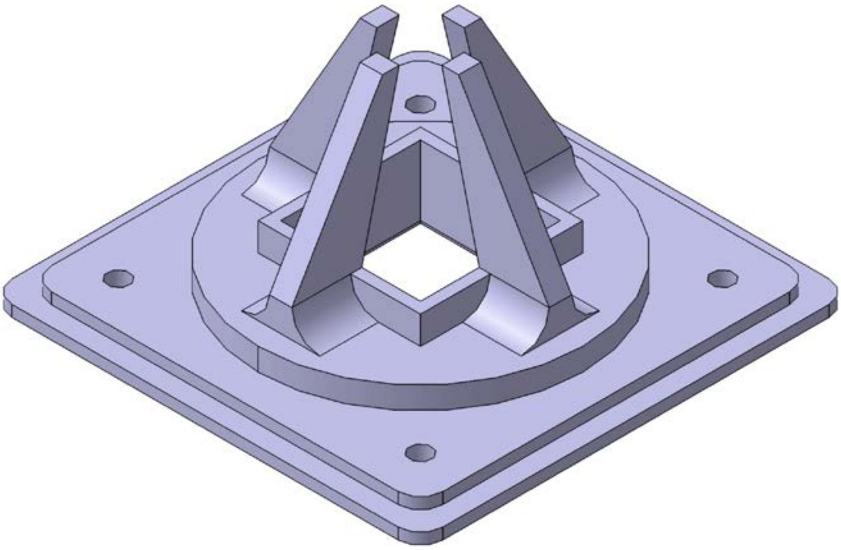
5.2 Transplanting

Transplant the germinated seeds from the styrofoam tray to the aeroponic system. Make sure that the roots have grown through the plug (picture 3, right) so they will be kept moist by the aeroponic system. This takes approximately 10 to 14 days for leafy greens, lettuce, tomato and pepper, but cucumber and radish will be faster (1 week). Wrap foam around the plugs and put it in the aeroponic system (picture 3, left).

DLR developed and produced ‘rock wool holders’ for the plugs to transplant the seedlings from tray to the aeroponic system (picture 4).



Picture 3: Lettuce Crispy green after transplanting (14 days after sowing). This was a test with the aeroponic system.



Picture 4: Rock wool holder to put in the plug with the seedling and transplant to the aeroponic system

The plants can be spaced to their final density (Table 8), or spaced gradually for the fruit vegetables to save space and increase the light use efficiency (Table 9).

Table 8: Plant density (plants m^{-2}) and crop management of different groups of crops

Group	Crop	Plant density (plants m^{-2})	Period sowing-harvest (weeks)	Management
Lettuce	All lettuce	83	4 weeks – 10 weeks	Spread harvest weekly
Leafy greens	Red mustard	625	4 weeks	
	Swiss chard	295	4 – 6 weeks	
	Rocket	333	4 – 6 weeks	
Radish	Radish	278-625	3 – 4 weeks	
Herbs	Chives	1875	6 – 16 weeks	regrowth
	Parsley	625	6 – 16 weeks	regrowth
Fruit veg.	Tomato dwarf	16.7	12 until > 17 weeks*	Ticking, bind up and harvest
	Tomato	8.3	14 weeks	Ticking, bind up and harvest
	Cucumber	8.3	7.5 >17 weeks	Bind up and harvest
	Pepper	8.3	17 until ?	Bind up and harvest

*First harvest 12 weeks after sowing and can be continued longer than 17 weeks after sowing (but it was not tested in Wageningen for a longer period than 17 weeks).

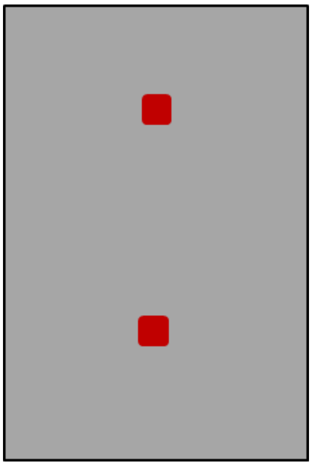
Table 9: Plant density for fruit vegetables at different stages

Crop	Days after sowing	Plant density (plants m^{-2})	Remark
Tomato dwarf	Sowing	1050	plugs
	12 -14	33	8 plants / tray*
	35	25	6 plants / tray
	56	16.7	4 plants / tray
Tomato	Sowing	1050	plugs
	12 - 14	33	8 plants / tray
	28	25	6 plants / tray
	42	12.5	3 plants / tray
	56	8.3	2 plants / tray
Cucumber	Sowing	1050	plugs
	7	33	8 plants / tray
	21	25	6 plants / tray
	28	12.5	3 plants / tray
	42	8.3	2 plants / tray
Pepper	Sowing	1050	plugs
	12	33	8 plants / tray
	35	25	6 plants / tray
	56	12.5	3 plants / tray
	70	8.3	2 plants / tray

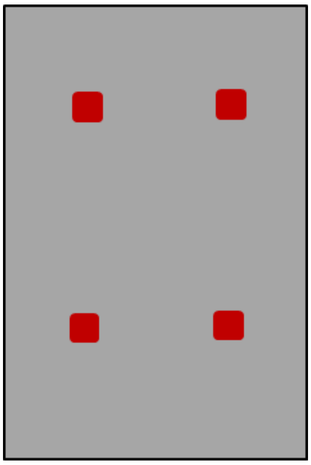
*A tray is 40 cm x 60 cm = 0.24 m^2

5.3 Spacing

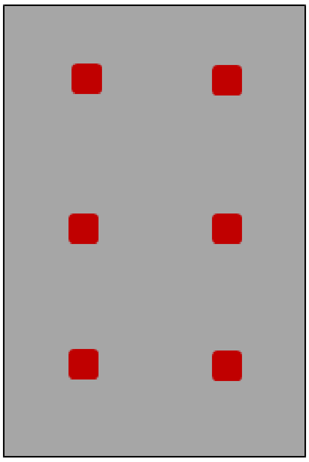
The final plant density for the various crops was set as follows:



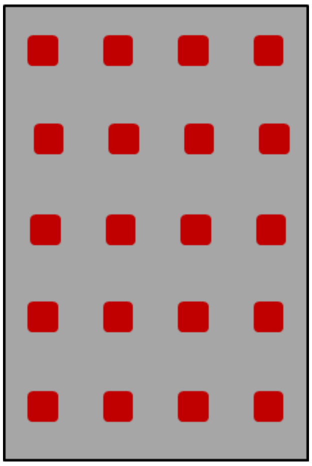
2 plants/tray:
Cucumber
Pepper
Tomato (indeterminate, 2 stems each)



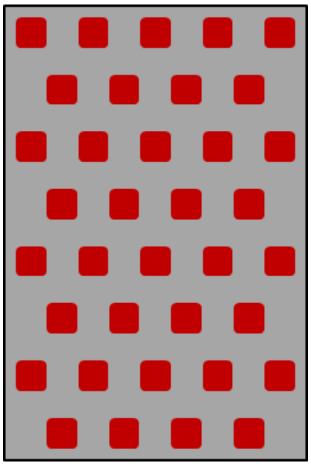
4 plants/tray:
Dwarf tomato (determinate)



6 plants/tray:
Lettuce
Single harvest



20 plants/tray:
Lettuce



36 plants/tray:
Spinach (Basil, Radish)

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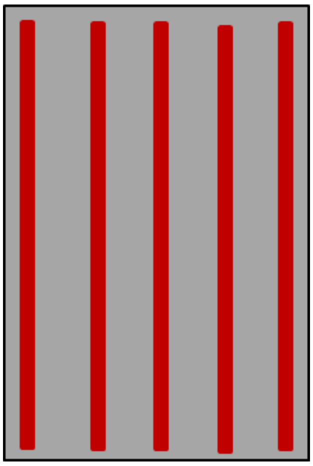
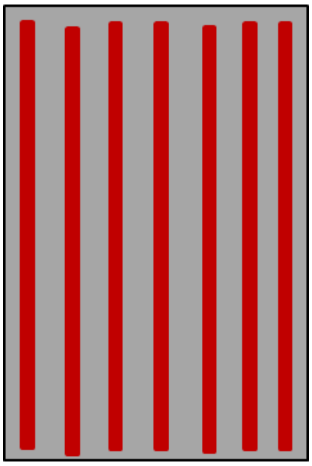


5 rows/tray*:
Rocket, Radish and Swiss chard (15 plants/row)



7 rows/tray*:
Chives (20 plugs/row; 3 seeds per plug)
Parsley and Red mustard (20 plants/row)

*Approximate numbers per row

5.4 Crop management and harvest

Crop development should be regularly monitored and after some experience abnormal appearance will be recognized. For example necrotic spots on leaves may indicate that the light intensity is too high, or wilting of plants might indicate an inadequate nutrient supply. In an aeroponic system, problems with pumps or blocked nozzles will immediately result in wilting of plants and plant death within a day. Other unrecognized abnormalities which may be disease symptoms should be photographed and checked with an expert. Preventing diseases and viruses is the best way: don't eat/bring fresh tomato or other fresh vegetables during travelling to Antarctica (all fresh tomatoes can contain pepino mosaic virus).

<u>Lettuce</u>

Lettuce can be cultivated at a high density of 83 plants m^{-2} (20 plants per tray) until the end of the cultivation. Spread harvest can commence four to five weeks after sowing at the moment that the plants touch each other and maximum soil cover is reached. The outer (1-3) leaves can be harvested from each plant and be eaten. Spread harvest can be carried out once or twice weekly until plants start to bolt. Bolting starts with a more rapid vertical growth of the plant (10 to 11 weeks after sowing, picture 5).

Picture 5: Spread harvest Lettuce Crispy Green Expertise. Twenty plants in a tray (above left), one plant (right) and bolting after 10-11 weeks (left).

<u>Leafy greens</u>

After transplanting the crops to the final system, the leafy greens, herbs and radish do not need management anymore. Leafy greens can be harvested and eaten after 4 to 6 weeks. Regrowth is possible but the quality of the plants is often less compared to the first harvest (observed in experiments in Wageningen). When additional harvests are desired following regrowth, make sure that the growing tip of the plant is not cut off.

Radish

When radish is cultivated in a high density (625 plants m^{-2}; 150 plants per tray), the plants at the border of the system can be eaten after 3 weeks; plants in the middle after 4 weeks. Using a lower plant density of 278 plant m^{-2}; 66 plant per tray) all plants can be eaten 3 weeks after sowing. The diameter of the taproot should be at least around 20 – 25 mm, but a diameter of 30 – 35 mm is also fine and tasty. Not only the taproot can be eaten, the leaves are also edible.

Herbs

Herbs can be harvested 6 weeks after sowing. Chives can be totally harvested; plants will regrow very easily and can be harvested again after 4 weeks. This can be repeated at least 3 times and probably more. When harvesting parsley; make sure that the youngest leaf is not cut off. This growing point will grow very easily and can be harvested again after 4 weeks. This can be repeated at least 3 times and probably more.

Fruit vegetables

Dwarf tomato plants are 'determinate' which means that the plant will stop growing in height after fruit set. Side shoots should not be removed but left to flower and produce fruits. Plants cultivated at 21/19°C form the first truss 5 weeks after sowing and will flower 1 to 2 weeks later. Use sticks or string to support the plant (picture 6). Flowers need to be 'ticked' or 'shaken' (by hand) daily to stimulate pollination, or use a mechanical vibrator. The first fruits can be harvested 12 weeks after sowing and can continue to be harvested for at least 17 weeks after sowing and probably for a longer period (a maximum period of 17 weeks was tested in Wageningen). Plants cultivated at 25/23°C will develop somewhat faster and the first fruit can be harvested 9 weeks after sowing.

Picture 6: Dwarf tomato (F1 2414) supported with a stick. New trusses are formed at side shoots.

A compact ‘indeterminate’ tomato will grow continuously in height and should be cultivated with 2 stems. In the juvenile stage, the main stem is cut just above the third leaf; two to three side shoots will appear. After 10 to 12 days retain the 2 best side shoots and remove the third. Two stems will continue to develop and other side shoots should be removed during cultivation. Use sticks or string (hanging system) to support the 2 stems. First fruits can be harvested 14 weeks after sowing. When plants become too tall, lower the plants (remove the oldest leaves) and keep a fixed distance between the top of the plant and the lamps.

Cucumber plants grow very rapidly and require binding (support) weekly. In our system in Wageningen plants were kept compact by winding the stem horizontally around 3 sticks. Pollination and fruit pruning are not necessary; fruit set will take place if the plants have enough assimilates and abortion will occur if assimilates are limiting. Fruits should be harvested when the final size has been reached: around 10 cm long. We harvested at fruit fresh weight of around 75 gram. If fruits remain longer on the plant, the setting of new fruits slows down which implies that daily harvests or harvests 4 times a week is required. Production will increase when fruits are harvested at around 60 gram per fruit (personal information RijkZwaan). First fruits were harvested 7.5 weeks after sowing. Plants cultivated at 25/23°C will develop somewhat faster and the first fruit can be harvested 6 weeks after sowing. Remove leaves that touch the tray, because this will create a humid zone and problems/diseases can occur. Remove also leaves below around 0.5 m the last picked fruit. When binding the stems around the sticks make sure that the stems do not touch the tray to prevent them of getting wet. We estimate a cultivation period of 6 month but could not test this in the facilities in Wageningen. But when the plants become too big and unmanageable, replace them earlier by new plants.

Pepper grows very slowly and it takes about 4 months to harvest the first fruits. The bushy pepper does not need any crop management. Pollination is easy (self-pollinator); it is not necessary to take any action. Larger cultivars (like Cupid) can be cultivated with 2 stems and pruning is necessary.
Method of pruning: after sowing the juvenile plant develops and makes around 8-10 leaves and then a flower will appear. In this phase, no pruning is necessary. After this first flower, more than 1 stem will develop. From this moment, pruning is necessary except for the bushy pepper (mini pepper; for EDEN 1601-M). After the first flower: keep the 2 best stems and remove the third or even more stems that appear at this position in the crop. These 2 stems will be maintained per plant. But when no pruning is done after this stage, these 2 stems will split again: in this way a compact bushy plant will appear like described above. So do the pruning for the 2 stems as follows: when a new side shoot appear, always keep the best shoot and from the other shoot keep one leaf and one flower and remove the rest. Continue this pruning during cultivation (weekly), because side shoots will appear continuously.

6 Production

The production is expressed in fresh weight per m^{-2} and for the fruit vegetables in fruits m^{-2} $week^{-1}$. The production of herbs, tomato and cucumber was measured during a period of 17 weeks after sowing and the experiment stopped. Production will continue after this period.

Production of the compact tomato is not included in this table, because this plant was tested in 'border trays'. So the production values are not representative for the climate conditions.

Table 10: Production (edible part of the plants) in fresh weight (kg m^{-2}) tested in different experiments

Crop	FW (kg m^{-2})	Duration (weeks)	Remark
Lettuce Crispy	25.2	11	Spread harvest
Red romaine lettuce	8.8	6	Spread harvest
Lettuce Batavia	8.3	6	Spread harvest
Rocket	6.2	4	Single harvest
Red Mustard	7.1	4	Single harvest
Swiss chard	7.9	6	Single harvest
Spinach Golden Eye	1.9	6	Single harvest
Radish: taproot	6.5 - 9.4*	3 - 4	Single harvest
Radish: leaf	3.7 - 3.4*	3 - 4	Single harvest
Chives	24.3	17	4 harvests (regrowth)
Parsley	16.8	17	4 harvests (regrowth)
Tomato F1 2414 (21°C)	1.59 ($week^{-1}$)		238 fruits m^{-2} $week^{-1}$ (6.7 g $fruit^{-1}$)
Tomato F1 1202 (21°C)	1.58 ($week^{-1}$)		180 fruits m^{-2} $week^{-1}$ (8.8 g $fruit^{-1}$)
Cucumber Quarto (21°C)	2.28 ($week^{-1}$)		30.2 fruits m^{-2} $week^{-1}$ (75 g $fruit^{-1}$)
Cucumber Picowell	2.58 ($week^{-1}$)		33.3 fruits m^{-2} $week^{-1}$ (77 g $fruit^{-1}$)

*cultivated at 300 and 600 µmol m^{-2} s^{-1} respectively

7 Summary of all crops

In the following summarizing tables, actions, settings and production are presented per crop.

Lettuce Crispy Green Expertise

Day	Action	
1	Climate after sowing	21/19°C, 750 ppm CO_2, 75/85 RH, 200 µmol m^{-2} s^{-1}
14	Transplanting	83 plants m^{-2} (20 plants per tray)
	Climate	21/19°C, 750 ppm CO_2, 75/85 RH, **300** µmol m^{-2} s^{-1}
28 – end	Crop management	Spread harvest (weekly or 2 times per week)
	First harvest	4 to 5 weeks after sowing
77	End harvest	11 weeks after sowing
77	Production FW (kg m^{-2})	25.2

Lettuce Romaine (Outredgeous) and Batavia (Othilie)

Day	Action	
1	Climate after sowing	21/19°C, 750 ppm CO_2, 75/85 RH, 200 µmol m^{-2} s^{-1}
14	Transplanting	83 plants m^{-2} (20 plants per tray)
	Climate	21/19°C, 750 ppm CO_2, 75/85 RH, **300** µmol m^{-2} s^{-1}
28 – end	Crop management	Spread harvest (weekly or 2 times per week)
	First harvest	4 to 5 weeks after sowing
77	End harvest	11 weeks after sowing
77	Production FW (kg m^{-2})	Not determined in Wageningen after 11 weeks. 8.8 and 8.3 kg m^{-2} for Outred. and batavia after 6 weeks

Rocket

Day	Action	
1	Climate after sowing	21/19°C, 750 ppm CO_2, 75/85 RH, 200 µmol m^{-2} s^{-1}
10 - 14	Transplanting	333 plants m^{-2} (80 plants per tray)
	Climate	21/19°C, 750 ppm CO_2, 75/85 RH, **300** µmol m^{-2} s^{-1}
28	Production FW (kg m^{-2})	6.2

Red Mustard

Day	Action	
1	Climate after sowing	21/19°C, 750 ppm CO_2, 75/85 RH, 200 µmol m^{-2} s^{-1}
10 - 14	Transplanting	625 plants m^{-2} (150 plants per tray)
	Climate	21/19°C, 750 ppm CO_2, 75/85 RH, **300** µmol m^{-2} s^{-1}
28	Production FW (kg m^{-2})	7.1

Swiss chard

Day	Action	
1	Climate after sowing	21/19°C, 750 ppm CO_2, 75/85 RH, 200 µmol m^{-2} s^{-1}
10 -14	Transplanting	295 plants m^{-2} (70 plants per tray)
	Climate	21/19°C, 750 ppm CO_2, 75/85 RH, **300** µmol m^{-2} s^{-1}
42	Production FW (kg m^{-2})	7.9

Spinach

Day	Action	
1	Climate after sowing	21/19°C, 750 ppm CO_2, 75/85 RH, 200 µmol m^{-2} s^{-1}
10 - 14	Transplanting	156 plants m^{-2} (37 plants per tray)
	Climate	21/19°C, 750 ppm CO_2, 75/85 RH, **300** µmol m^{-2} s^{-1}
42	Production FW (kg m^{-2})	1.9

Radish

Day	Action	
1	Climate after sowing	21/19°C, 750 ppm CO_2, 75/85 RH, 200 µmol m^{-2} s^{-1}
7	Transplanting	278 plants m^{-2} (66 plants per tray)
	Climate	21/19°C, 750 ppm CO_2, 75/85 RH, **600** µmol m^{-2} s^{-1}
21	Production FW (kg m^{-2})	Taproot: 9.4
		Leaf: 3.4

Chives

Day	Action	
1	Climate after sowing	21/19°C, 750 ppm CO_2, 75/85 RH, 200 µmol m^{-2} s^{-1}
10 - 14	Transplanting	1875 plants m^{-2} (450 plants per tray)
	Climate	21/19°C, 750 ppm CO_2, 75/85 RH, **600** µmol m^{-2} s^{-1}
42	Production FW (kg m^{-2})	2.1 (first harvest)
71	Cumulative FW (kg m^{-2})	7.6 (after regrowth)
97	Cumulative FW (kg m^{-2})	14.8
119	Cumulative FW (kg m^{-2})	19.4
...		Regrowth can be continued

Parsley

Day	Action	
1	Climate after sowing	21/19°C, 750 ppm CO_2, 75/85 RH, 200 µmol m^{-2} s^{-1}
10 - 14	Transplanting	625 plants m^{-2} (150 plants per tray)
	Climate	21/19°C, 750 ppm CO_2, 75/85 RH, **300** µmol m^{-2} s^{-1}
42	Production FW (kg m^{-2})	0.86 (first harvest)
71	Cumulative FW (kg m^{-2})	6.26 (after regrowth)
97	Cumulative FW (kg m^{-2})	12.25
119	Cumulative FW (kg m^{-2})	16.66
...		Regrowth can be continued

Dwarf tomato (determinate)

Day	Action	
1	Climate after sowing	21/19°C, 750 ppm CO_2, 75/85 RH, 200 µmol m^{-2} s^{-1}
12-14	Transplanting	33 plant m^{-2} (8 plants per tray)
	Climate	21/19°C, 750 ppm CO_2, 75/85 RH, **300** µmol m^{-2} s^{-1}
35	Density	25 plants m^{-2} (6 plants per tray)
56	Density	16.7 plants m^{-2} (4 plants per tray)
	Nutrient solution	Change recipe in case you used the recipe for veg. crops
Daily	Pollination	'Ticking' the trusses or mechanical vibration
84 - *	Production FW (kg m^{-2})	Around 1.59 ($week^{-1}$)
	Production FW (fruits m^{-2})	180 – 238 fruits m^{-2} $week^{-1}$ (7 – 9 g $fruit^{-1}$)

* maximum production period was not determined

Compact indeterminate tomato (Candy Tom)

Day	Action	
1	Climate after sowing	21/19°C, 750 ppm CO_2, 75/85 RH, 200 µmol m^{-2} s^{-1}
12-14	Transplanting	33 plant m^{-2} (8 plants per tray)
	Climate	21/19°C, 750 ppm CO_2, 75/85 RH, **300** µmol m^{-2} s^{-1}
28	Density	25 plants m^{-2} (6 plants per tray)
30 - 40	Top	Remove main stem above third leaf
42	Transplanting	Remain 2 stems
	Density	12.5 plants m^{-2} (3 plants per tray)
Daily	Pollination	'Ticking' the trusses or mechanical vibration
56	Density	8.3 plants m^{-2} (2 plants per tray)
	Nutrient solution	Change recipe in case you used the recipe for veg. crops
		Remove side shoots weekly
100	Production FW (kg m^{-2})	Not measured in Wageningen

Cucumber

Day	Action	
1	Climate after sowing	21/19°C, 750 ppm CO_2, 75/85 RH, 200 µmol m^{-2} s^{-1}
7	Transplanting	33 plant m^{-2} (8 plants per tray)
	Climate	21/19°C, 750 ppm CO_2, 75/85 RH, **300** µmol m^{-2} s^{-1}
21	Density	25 plants m^{-2} (4 plants per tray)
28	Density	12.5 plants m^{-2} (3 plants per tray)
42	Density	8.3 plants m^{-2} (2 plants per tray)
	Nutrient solution	Change recipe in case you used the recipe for veg. crops
53 - *	Production FW (kg m^{-2})	Around 2.45 ($week^{-1}$)
	Production FW (fruits m^{-2})	30 - 33 fruits m^{-2} $week^{-1}$ (76 g $fruit^{-1}$)

* maximum production period was not determined

Pepper

Day	Action	
1	Climate after sowing	21/19°C, 750 ppm CO_2, 75/85 RH, 200 µmol m^{-2} s^{-1}
14 - 20	Transplanting	33 plant m^{-2} (8 plants per tray)
	Climate	21/19°C, 750 ppm CO_2, 75/85 RH, **300** µmol m^{-2} s^{-1}
35	Density	25 plants m^{-2} (4 plants per tray)
56	Density	12.5 plants m^{-2} (3 plants per tray)
70	Density	8.3 plants m^{-2} (2 plants per tray)
90	Nutrient solution	Change recipe in case you used the recipe for veg. crops
➢ 120	Production FW (kg m^{-2})	Not determined

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