Comparative study of basil cultivation in Fieldlab Vertical Farming

Second comparative trial on the cultivation of basil in vertical farm cells at Delphy Improvement Centre, Logiqs, Vertify & Philips Horticulture LED Solutions

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Referaat
Binnen het Fieldlab Vertical Farming is vergelijkend onderzoek gedaan naar de teelt van basilicum in de indoor farming cellen van Delphy Improvement Centre, Philips Horticulture LED Solutions (Signify), Vertify en Logiqs. Ondanks dezelfde klimaatinstellingen ontstonden er na een teeltduur van 28 dagen grote verschillen tussen de planten. Planten uit de ene cel waren langwerpiger dan andere. Planten uit verschillende cellen met een vergelijkbaar versgewicht hadden een verschillende verdeling van biomassa over de bladeren en stengels. We vonden temperatuurverschillen tussen macro- en microklimaat tussen cellen en in de loop van de tijd, met lagere bladtemperaturen dan ruimtetemperaturen, opvallend genoeg vooral ook in het donker. De mate waarin het macro- en microklimaat verschillen, lijken te worden bepaald door het technische ontwerp van de cel.

Abstract
Within the Vertical Farming Fieldlab, comparative research has been conducted into the cultivation of basil in the indoor farming cells of Delphy Improvement Centre, Philips Horticulture LED Solutions (Signify), Vertify and Logiqs. Despite the same climate settings, major differences emerged between the plants after a cultivation period of 28 days. Plants from one cell were more elongated than others. Plants from different cells with similar fresh weight had different biomass distribution between leaves and stems. We found temperature differences between macro- and microclimate between cells and over time, with lower leaf temperatures than room temperatures, striking enough especially in the dark. The extent to which the macro and micro climate differ appears to be determined by the technical design of the cell.

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Summary

Within the Fieldlab Vertical Farming, a comparative study on the cultivation of basil was conducted in the indoor cells of participants Delphy Improvement Centre, Philips Horticulture LED Solutions (Signify), Vertify and Logiqs. The cells are different in size and technical set-up. This study was done to test the following research question:

- If we use the same input settings in all four cells, do we realize the same macroclimate conditions (in the space above the plants)?
- Do we realize the same microclimate conditions (between the plants)?
- Do we realize the same plants in terms of morphology, weight and quality at the end of the trial?

This study is a follow up of an earlier comparative study between the cells of WUR Bleiswijk and Delphy within Fieldlab Vertical farming.

In this experiment we cultivated basil with the exact same growing recipe for the four participating locations in terms of light, climate and fertigation. Although the climate setpoints were the same, some differences in macroclimate between the cells were observed. The difference (ΔT) between temperature on cell level (macroclimate) and temperature on plant level (microclimate) was different among the cells, and differed between different moments in time. Notable was that the leaf temperature was lower than the air temperature, and that this difference was in most cases bigger in the dark period rather than in the periods with the LED lights on.

The plants grown in the different cells were quite different at the end of the trial, after 28 days. The plants grown in the cell of Signify were remarkably more elongated than from the other cells. The plants of Delphy had a similar fresh weight to those of Signify, but the biomass distribution was different with a higher percentage of biomass allocated to the leaves in Delphy's plants.

The differences found between the cells were the result of the influences of the growing environment on the plants. This resulted in a microclimate in the canopy that was different from the climate computer controlled macroclimate in the cells. The extent to which the macro- and microclimate differs, seems to be determined by the technical design of the facility.

1 Introduction and objectives

1.1 Introduction

Within WP2 of the project Fieldlab Vertical Farming a brainstorm session with the partners lead to the idea of comparative studies. These studies should answer the question: do equal inputs lead automatically to equal outputs in vertical or indoor farming? Vertical farms have the premise that, because of the total control of the conditions for plant growing, a standard recipe will lead to plants with standard size, morphology and quality, no matter where the plant is geographically produced. However, some practical experiences show that this level of standardization and reproducibility has not been reached yet.

In the first comparison study, the cultivation of basil was researched in cells of Delphy and WUR, both in Bleiswijk. This first study indeed showed that equal inputs and settings could lead to different plants (Meulendijks and Bijlaard, 2020).

Figure 1 *Do the same inputs lead to the same outputs?*

There are two aspects to the question. First, the output and plant performance can differ by equal climate settings because the specification of the cells can be given based on different protocols. Meaning that the way the climate in the cells is set, monitored and controlled can be different and therefore the realized climate can differ between cells. Secondly, the design of the cells can be different which could result in different experiences for the crop climate wise, even when the plants are equal in the end.

Within WP2 the plan was raised to work both on standardizing the measurement protocols as well as working mapping the differences in cultivation results, including the attempt to search for explanations for the differences. The first comparison study was done between the cells at WUR and Delphy, this second study was done including more partners of the project.

1.2 Goal

The goal of this trial is to test the following hypothesis: an equal growing recipe in different indoor cells can result in different crops (growing development) to confirm the result found in the first comparison study. The hypothesis was tested in the climate cells at Delphy Improvement Centre (also to mentioned: Delphy), Logiqs, Philips Horticulture LED Solutions (also to be mentioned: Signify), and Vertify.

Research questions are:

1. Do we find a measurable difference in plant growth and development among the different cells? If yes, Which morphological differences were observed? Can we relate those differences to measured climate parameters?
2. What are the design differences between the cells and can they explain (part) of the plant differences observed and measured?

2 Material and methods

2.1 Framework

The idea behind the framework is that climate settings will lead to a certain desired macroclimate in the indoor cell. The microclimate, the climate in the canopy, just around the leaves of the plants, is determined by the macroclimate and the plant itself. The microclimate is the climate that the plants experience; this will influence growth and development, leading to a plant of certain characteristics.

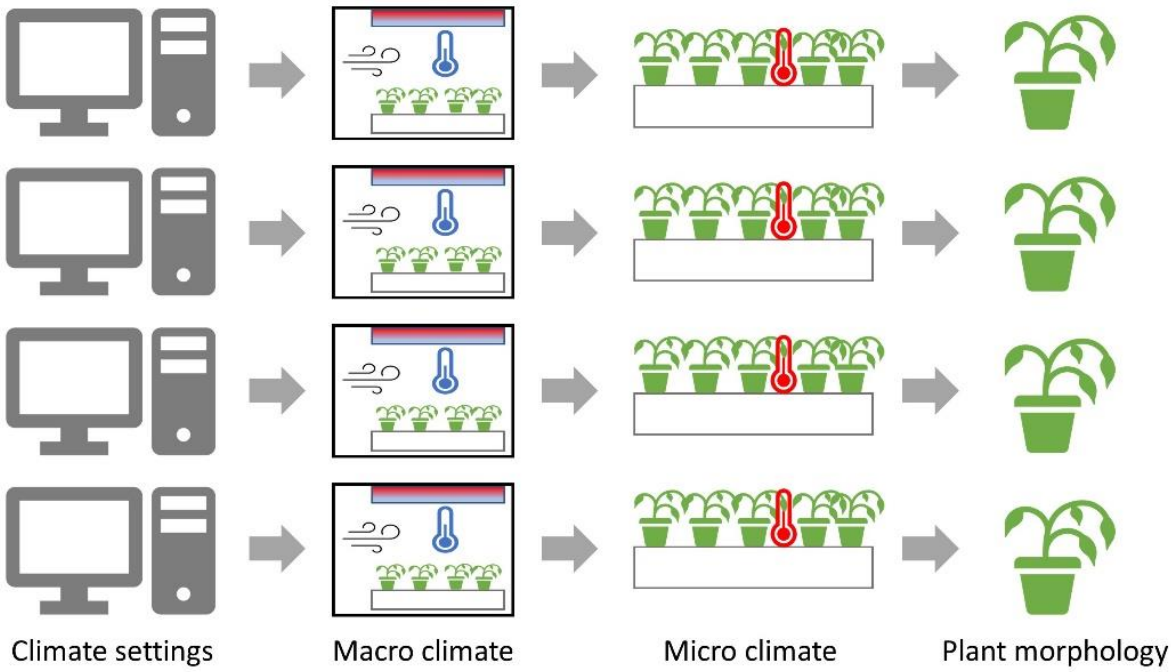

Figure 2 *Schematic overview of the framework.*

In this study, we installed the same climate setpoints and measured macroclimate, microclimate and plant characteristics. If we should find differences in plant characteristics, it must be able to track down the phase in the described process where the differences arise. In the previous study (reported by Meulendijks and Bijlaard), the hypotheses was formulated that the design of the cells and the technical setup are probably responsible for the emergence of differences in microclimate.

2.2 Material and trial set-up

This trial is conducted in the climate cells at different locations, namely Delphy (Bleiswijk), Logiqs (Maasdijk), Signify (Eindhoven) and Vertify (Naaldwijk). Table 1 Characteristics plant material, Table 2 Climate settings and Table 3 Characteristics of the climate chambers.

Table 1 *Characteristics plant material.*

Aspect	in trial
Crop	Basilicum in pots(13cm)
Variety	Keira – Enza zaden
Supplier	Gipmans
Sowing date	2nd March 2021 (Delphy) & 23rd March (Signify, Vertify & Logiqs)
Growing cycle	28 days (exc. Germination period)
Plant density	30 pots per m^2

Table 2 *Climate settings.*

Aspect	in trial
Daylength	16 hours
PPFD	220 umol/s/m^2 PAR ratio red/blue 90/10/ +5%FR
Temperature (D/N)	28-24 °C
RV (D/N)	75/85%
CO_2 (D/N)	1000/ambient ppm
EC	2,0
pH	6,0
Air speed	1,5 cm/s at air inlet

Table 3 *Characteristics of the climate chambers.*

	Delphy	Signify	Vertify	Logiqs
Climate chaimber	F1	P1	WHC	POD-1
Volume cell	31 m^3	98 m^3	60 m^3	2,77 m^3
Nett cultivation surface	4.8 m^2	22 m^2	15,6 m^2	5,76 m^2
#layers	2	2 (3 in the cell)	3	1
Distance table - lamp	1.0 m	45cm and 85 cm	60 cm	48 cm
Supplier/builder	Certhon		Green Simplicity	Logiqs
Type airflow	1 side perforated wall	perforated wall	perforated flexible tube	The Logiqs airflow
LED's	Signify Dynamic PM 2.1	Signify Dynamic PM 2.1	HORTILED Multi 4DIM	LuminaidPX
Sensorbox climate	Dry-wet bulb	electronic	electronic	electronic

2.3 Measurements

The climate boxes, measuring temperature and humidity, installed in the different cells were not calibrated before the trial, because they are fixed in the cells. For light spectrum and intensity and air speed measurements (handheld devices) all partners used their own sensors to set the required spectrum and intensity. These sensors were not calibrated before the trial. Sensors for microclimate measurements (Micro-Lite; non-ventilated T and RH measurements) were calibrated before they were placed. Organizing one calibration day is difficult because the partners use it for multiple purposes and some instruments are attached to the table or something else in the cell.

Non-destructive plant measurements during the experiment:

Table 4 *Overview of non-destructive measurements.*

Parameter	Frequency measurement	Sensor
Temperature – macro	Continuous	Measurement box
Temperature – micro	Continuous (15min.)	Fourtec MicroLite datalogger
Relative humidity % – macro	Continuous	Measurement box
Relative humidity % – micro	Continuous (15min.)	Fourtec MicroLite datalogger
Leaf temperature	Every 5 days	Hand infrared T sensor
Windspeed	Every 5 days	Individual sensors per partner example: Testo 405i and 410i
Plant height	Every 5 days	Ruler

At the end of the experiment, the following destructive measurements were done:

Table 5 *Overview destructive measurements.*

Quantitative traits	unit
plant height	cm
pot Hypocotyl height2	cm
pot 1st node height2	cm
pot 2nd node height2	cm
stems <5 cm	#
stems > 5 cm	#
stems total	#
total fresh weight	g
leaf fresh weight	g
stem fresh weight	g
pot substrate weight	g
leaf dry weight	g
stem dry weight	g
Qualitative traits	unit
Decoloration*	1-5 scale
Cupping*	1-5 scale
Stem strength*	1-5 scale
roottips quality*	1-5 scale
roots amount*	1-5 scale

*Qualitative traits are scored a 1-5 scale. For example stem strength: 1 being very weak and 5 being very strong. Weak stems will bend and look faded, strong stems stay upright and look fresh and healthy. The picture in Annex 1 shows 3 pots. From left to right; strong stems (5) to weak stems (1) and the pot in between is medium strong (3).

2.4 Measurement set-up

In all cells measurement pots were determined and dataloggers were placed in between the crop to monitor microclimate per 15 minutes. Microclimate is defined as the climate in between the plants under the canopy. Of all the measurement pots, plant growth in time was measured every 5 days. The dataloggers were placed at pot height, see Photo 1. The basil plants grew fast and formed soon a solid plant layer. The loggers made it possible to measure what was going on in the canopy.

Photo 1 *Datalogger between pots with very small basil plants.*

3 Results and Discussion

3.1 Results macroclimate

In Figure 3, the macro climate temperature at the partners Signify, Vertify, Delphy and Logiqs during the cultivation period is shown. The climate at Logiqs is not following the same trend as the other partners. Their cell design is very different from the other partners' cells, especially for the air inlet. Because the air inlet at Logiqs in coming from the bottom of the table, they are measuring macro climate underneath the canopy, away from the light.

At the other three partners, the temperature looks stable over time, except for 2 periods due to technical disturbances at Vertify.

Figure 3 *Macro climate temperature at the partners Signify, Vertify, Delphy and Logiqs during the cultivation period of the basil.*

Figure 4 shows the macroclimate relative humidity in the cells during the cultivation period at the partners Signify, Vertify and Delphy. The pattern of the relative humidity is quite similar at Signify and Delphy, whereas at Vertify it shows a different pattern.

Figure 4 *Macro climate relative humidity at the partners Signify, Vertify, Delphy and Logiqs during the cultivation period of the basil.*

In these graphs we see that the realized macroclimate is not the same in the different cells. The questions are why this is not the same and if and how this affects microclimate and plant development.

3.2 Results Microclimate

In general, we observed the microclimate is starting to deviate from the macroclimate when the canopy of the crop closes. Before that moment, the data loggers are somewhat warmed-up by the radiation from the LED's. (The dataloggers were non-ventilated measurement devices, sensitive to radiation heat and to cooling by transpiration of the crop).

Another observation is that the microclimate varies slightly within cells, between cultivation layers. This is especially in air speed at canopy height. Differences become bigger when the canopy closes.

Figure 5 shows the macro and microclimate temperature in the cell at one of the partners, demonstrating the development over time and the differences between micro and macroclimate over time.

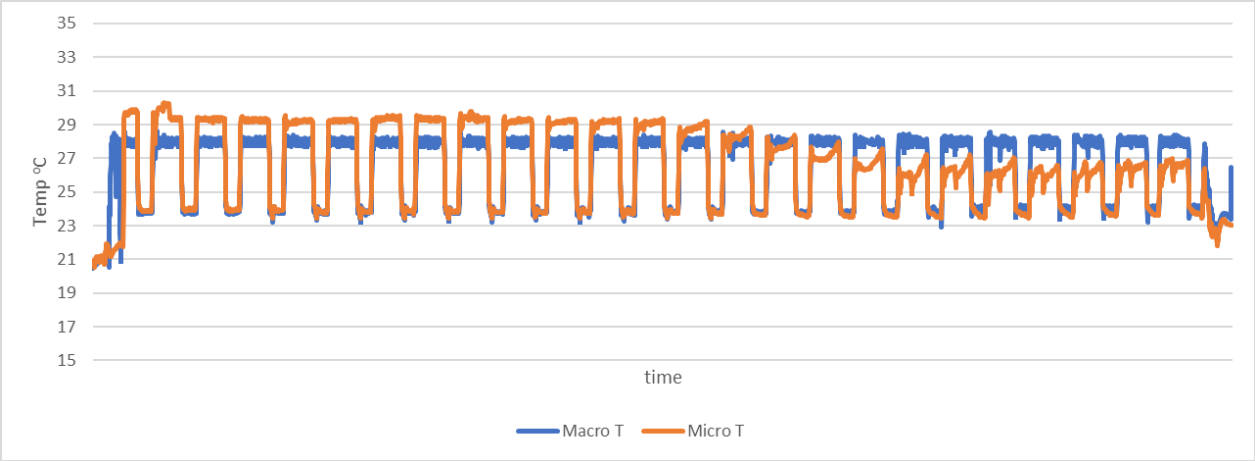

Figure 5 *Micro and macro temperature in the cell during the trial.*

Figure 6 shows the development and differences of the relative humidity in the macro and microclimate. The bigger the plants, the higher the humidity in between the canopy and the lower the temperature when the lights are on.

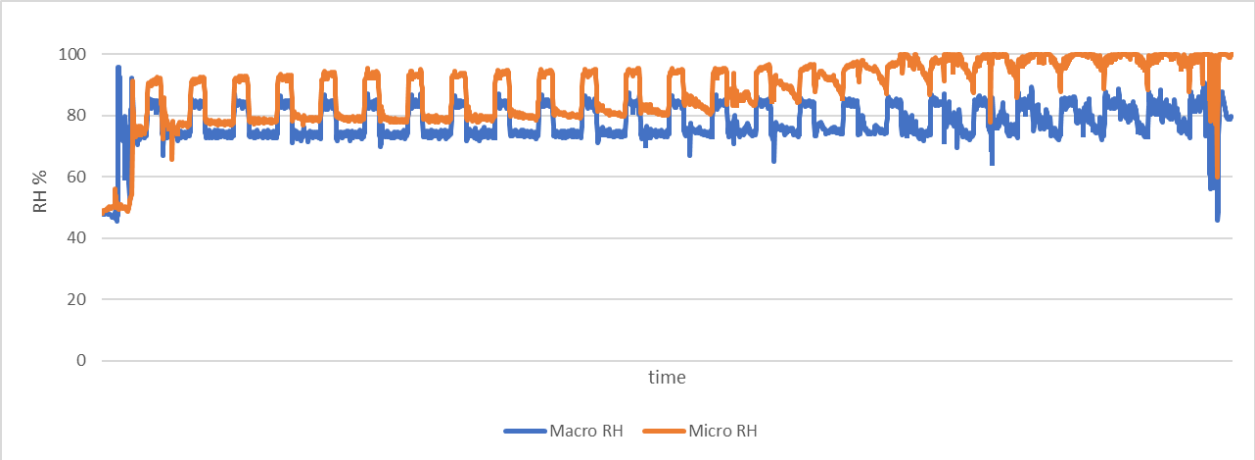

Figure 6 *Micro and macro relative humidity in the cell during the trial.*

If we look at the ΔT in the different cells it gives us Figure 7. ΔT is calculated as macro temperature – micro temperature.

For the other cells we found that at the start of the trial the microclimate temperature, when lights were on, was higher than the macro temperature, giving us a negative ΔT. This is due to fact that the dataloggers are heated up by the lamps. How much they heat up differs per cell, probably because of the different distances between the cultivation table and the lamps. On day 7 at Vertify we observed in all 3 cells that at night the ΔT has a high positive value, meaning the micro temperature is lower than the macro temperature.

At day 12, micro and macro temperature are quite similar except for 1 degree heating up at Delphy and Signify. On day 19, only at Delphy the dataloggers are heated up by the lamps, at Vertify and Signify the loggers recorded a lower temperature than the climate boxes. This transition might be explained by the plant growth, covering the dataloggers by this time. Also on day 19, but then at night, we see lower microclimate temperatures than macroclimate temperatures in all cells. In some cells more than in others. By this time, we have also measured higher RH values (Figure 6) in the macroclimate compared to the microclimate and earlier in the trial. Together these observations suggest transpiration at night, cooling the plants.

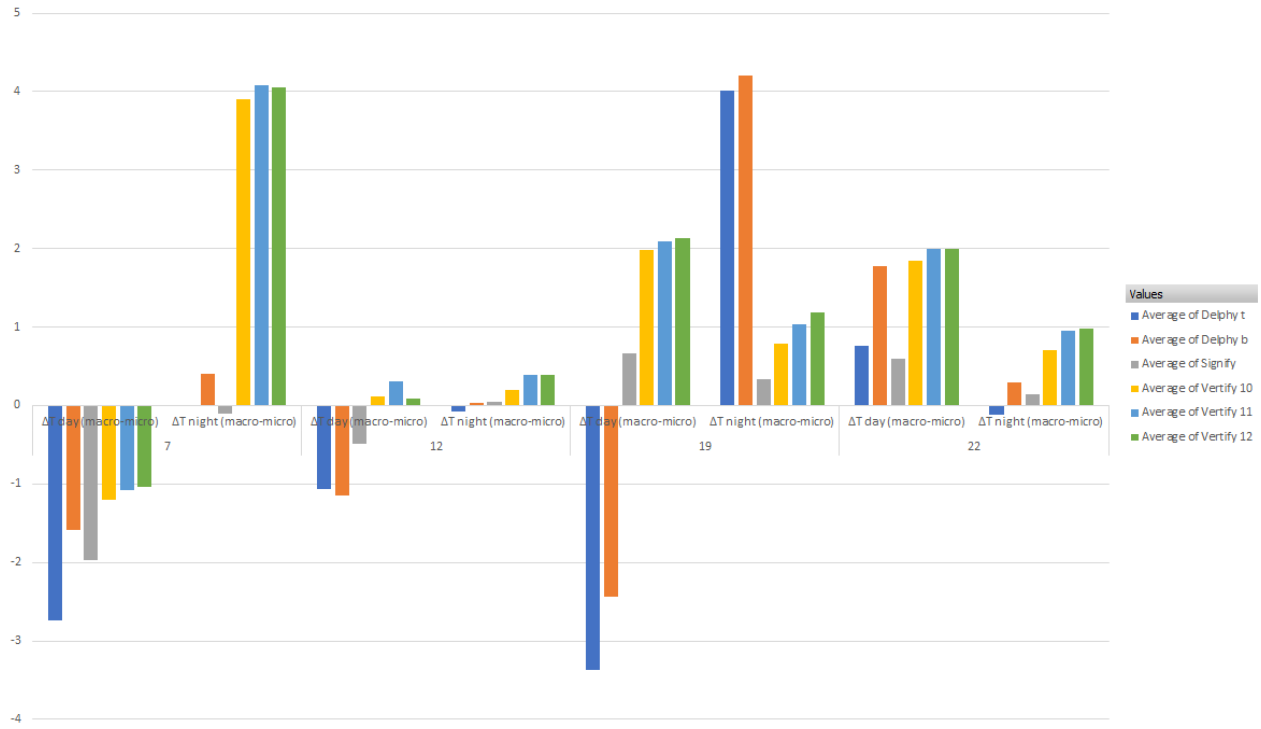

Figure 7 *Temperature differences between macro and microclimate per cell and measurement day.*

For Logiqs the climate box for measuring macro climate is located at the level of the microclimate at the other cells. This is underneath the canopy. The dataloggers for measuring the microclimate were placed above the canopy. Since the dataloggers are non-ventilated sensors, they are heated up by the lamps during the entire cultivation period. Meaning that we have ventilated measurements from under the canopy and non-ventilated measurements from above the canopy. That is why we cannot compare them to the other cells.

Leaf temperature measurements confirm lower leaf temperature compared to the macroclimate, see Figure 8. The leaf temperature is affected by air temperature (convective heat), radiant heat and transpiration (latent heat); but also by air flow/ air speed.

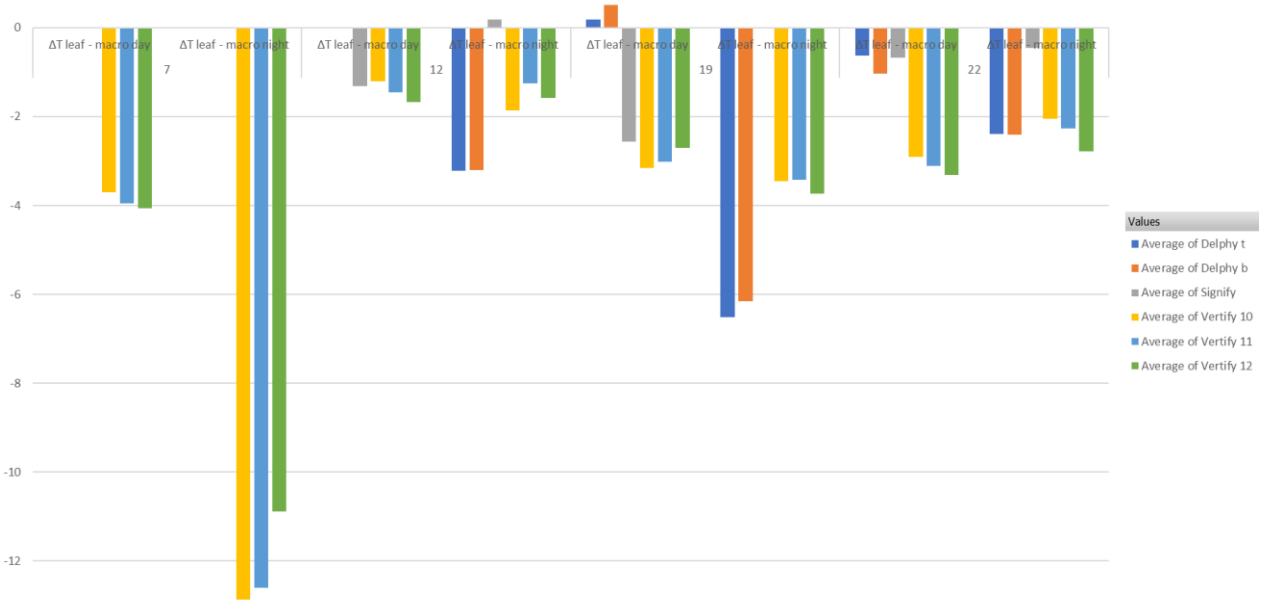

Figure 8 *Difference between leaf temperature and macro climate temperature per measurement day.*

In Figure 9 the air speed per cell and layer is shown per measurement day if measured at the location. This shows that the actual air speed at canopy height varies when the setpoint is the same for all cells.

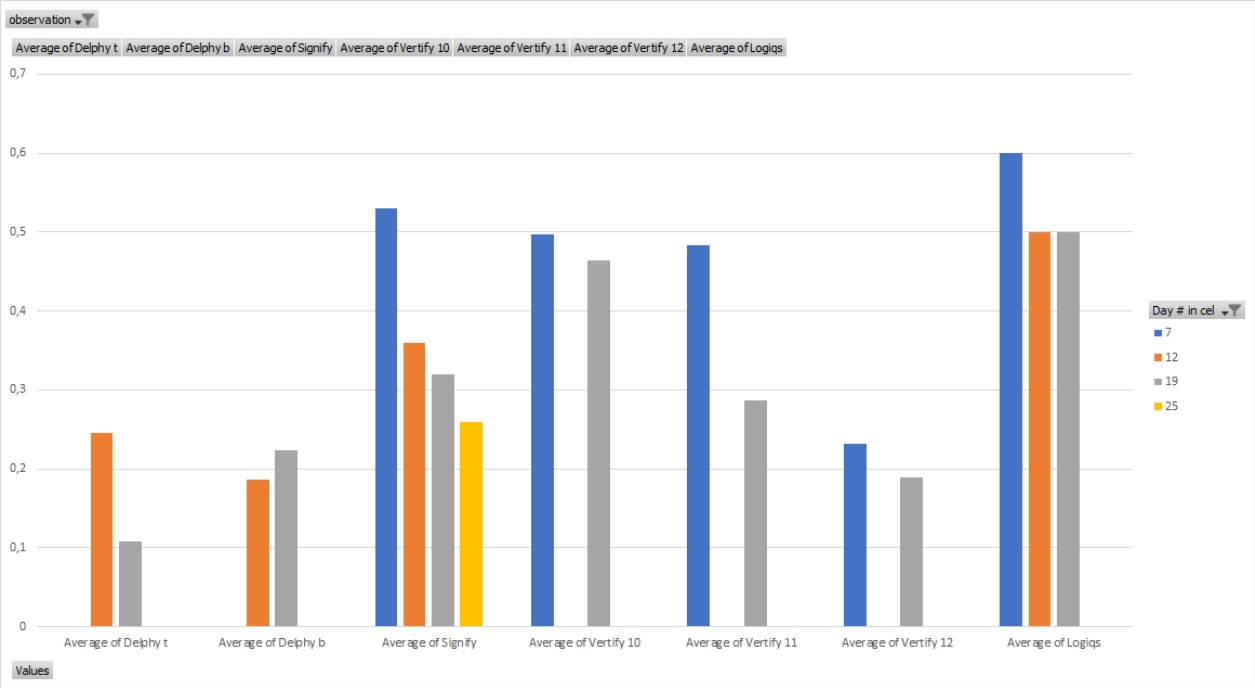

Figure 9 *Air speed in m/s per measurement day (day 7, 12, 19 and 25) at canopy level in the different cells. At Logiqs this is measured under the canopy, at the other locations above the canopy.*

3.3 Results plant measurements

During the trial, plant length and leaf temperature were measured from designated measurement plants. In Figure 10 we see the growth at all partners during the trial. We see that the plants at Delphy and Vertify follow roughly the same growth rate, where Logiqs is slower at day 19 and 22 but catches up at the end of the trial.

At Signify, the plant growth is higher from day 19 until the end. At the harvest day, the plants at Signify have grown past the lamp height, causing some leaf damage.

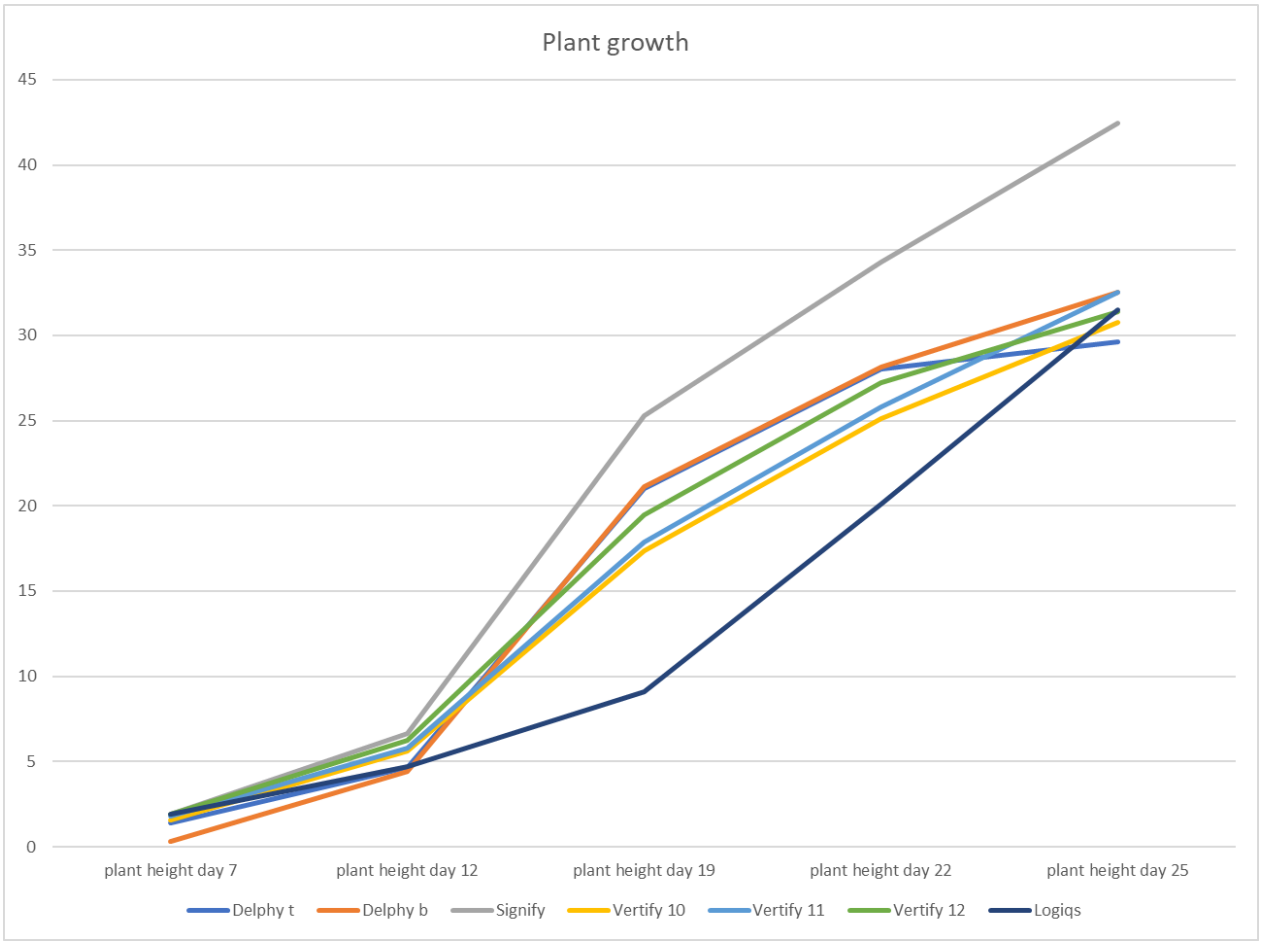

Figure 10 *Plant growth in cm measured during the cultivation period at the measurement days (day 7, 12, 19, 22 and 25).*

At harvest, several measurements were taken, both quantitative and qualitative. The qualitative traits were scored on a 1-5 scale to be able to compare the results.

The first comparison is made for plant height and the weight of the plants, including the distribution of fresh weight between the stem and the leaves (Figure 11).

Logiqs and Vertify have the lowest and comparable fresh weight, but the fresh weight distribution is quite different. Where at Logiqs the distribution between leaf and stem is almost 50-50, the plants at Vertify have a higher leaf percentage in all locations. Plant development in the cells is quite different, different numbers of leaves were formed. Final plant height, as shown in Figure 10 and Figure 11, is clearly highest at Signify. Considering the plant height and the cultivation area (distance from the table to the lamps), the plants at Signify should have been harvested earlier for higher quality. The plants at Delphy have the highest leaf weight in both locations, higher number of leaf pairs results in this.

Figure 11 *Plant height at harvest in cm, total fresh weight and weight distribution of leaf and stem in the different cells in grams.*

Table 6 summarizes the measurements of the destructive harvest at the end of the trial.

In this table we see that the total number of basil stems per pot is quite similar at all partners, however the architecture of the stems is vastly different. Logiqs for example had almost no small stems (< 5cm). At Delphy the height of the first and second nodes were lowest (not measured at Signify). The plants at Delphy formed the most leaves and nodes. Plants at Logiqs and Vertify were more streched and developed less leaves.

Quality of the products were also different in the different cells for cupping of the leaves. This occurred least at Delphy (no data for Signify).

Table 6 *Measurements at destructive harvest.*

Qualitative traits		**Delphy**	**Logiqs**	**Signify**	**Vertify**
plant height	cm	31,09	28,15	42,45	31,57
pot Hypocotyl height2	cm	4,80	5,24	6,44	6,06
pot 1st node height2	cm	9,22	17,65		15,14
pot 2nd node height2	cm	18,03	25,38		24,58
stems <5 cm	#	5,16	0,96	4,70	5,37
stems > 5 cm	#	15,34	22,22	17,25	13,70
stems total	#	20,50	22,89	21,95	19,07
total fresh weight	g	87,46	59,58	88,09	56,78
leaf fresh weight	g	59,64	29,19	48,46	39,44
stem fresh weight	g	26,86	30,39	39,63	17,34
pot substrate weight	g	311,86	421,84		438,74
leaf dry weight	g	4,35	3,62	3,43	3,17
stem dry weight	g	1,66	2,31	1,97	1,18
		Delphy	Logiqs	Signify	Vertify
decoloration	1-5 scale	1,41	1,86		1,00
cupping	1-5 scale	1,78	3,81		4,63
strength	1-5 scale	3,13	3,61		4,37
roottips quality	1-5 scale	2,50	4,31	4,15	4,07
roots amount	1-5 scale	3,53	4,50		3,70

4 Conclusions

Observations in the first comparison study reported by (Meulendijks & Bijlaard, 2020) were replicated in this trial as well. Deviations in e.g. plant morphology were even bigger than we found in the first trial.

Macroclimate.

- Although the climate settings were supposed to be the same, we saw some differences among the different cells. Especially the RH in the Vertify cell was different from the RH at Delphy and Signify. At Logiqs, the cell set up is so different from the others that the results are not comparable for climate below and above canopy to the other cells.

Microclimate was different in the different cells when using the same macro climate set points.

- Differences in microclimate temperature: ΔT between macro and microclimate differs from 1 to 4 degrees Celsius. Even more interesting: in some periods (day 12 and 19, lights on) the ΔT was positive in cells of some partners, and negative in cells of another partner.
- Also, the ΔT between the leaf temperature and micro/macroclimate temperature were different between different cells up to about 2°C.
- The wind speed at canopy level decreased as the plants grew. Both the instantaneous wind speed and the decrease of the wind speed during cultivation differed between the cells.

Plant development.

- Differences in height, weight, and biomass distribution over leaves and stems, development of stem and leaves and quality of the leaves.

All the observed differences could be caused by the construction and set-up and even color of the cells, see Appendix 1; schematic overviews of the cells. Not only the cultivation area differed in size, but also the set-up of the cells varies a lot. This results in different wind direction and speed, different distances of the plants to the lamps and differences in microclimate between the plants with the same macroclimate set points.

We need to know the system we use and the influence of that system on the climate and the plants.

However, we also need to be sure that the macroclimate in all the cells is the same, as controlled by the climate computer on the desired settings. In this trial, temperature was quite equal in the different cells, but for the RH the cells of at least one of the partners deviated from the rest. Data on the CO_2 levels was not collected in all cells. For photosynthesis and biomass production this is a shortcoming. However, the striking differences in plant morphology we observed in this trial cannot only be explained by any differences in CO_2 levels.

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Annex 1 Picture to indicate stem strength

The picture shows 3 pots. Left: strong stems (5). Middle: medium strong stems (3). Right: weak stems (1).

To explore the potential of nature to improve the quality of life

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