Enhancing greenhouse Horticulture in the Bekaa Valley, Lebanon

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Abstract
Efficiënt omgaan met water is in aride gebieden zeer belangrijk. Het toepassen van beschermde teelten helpt in de tuinbouw de productie te verhogen bij hetzelfde waterverbruik, terwijl mens en milieu er op vooruitgaan. In dit project is een Demo centrum ontwikkeld om nieuwe ontwikkelingen direct aan de telers te kunnen laten zien. Het ontwerp is gebaseerd op een computersimulatie van het lokale klimaat in de Bekaa vallei. Twee verbeterde en twee traditionele tunnels zijn vervolgens gebouwd. In elk van de twee typen is één tunnel voor de teelt in grond en de ander voor de teelt in substraat. De eerste teelt startte in April 2018 met tomaat en werd gevolgd door een komkommerteelt in oktober. Door de korte teeltduur kunnen alleen voorlopige conclusies worden gegeven. Het toepassen van passieve verwarming leidde in april tot 3oC hogere nachttemperaturen, verder was het klimaat in beide typen tunnels vergelijkbaar. Toch was de oogst in de verbeterde tunnels 40% hoger omdat de bestuiving met hommels de vruchtzetting en uitgroei enorm verbeterde. Het waterverbruik kon nog niet optimaal worden gedemonstreerd vanwege technische problemen.

Abstract
Water use efficiency in agriculture is crucially important in (semi-arid) regions. Greenhouse technology helps by combining a similar water consumption at a much higher yield, a better livelihood and labour opportunities. In this project, a demo centre was designed to disseminate innovations directly to growers. Design was based on computer simulations using local climate data. Two improved, span shaped, greenhouses and two traditional tunnels have been constructed in the Bekaa Valley. Cultivation is both in soil and in substrate, thus showing four steps in innovation. Cultivation started in April 2018 with tomatoes, followed by cucumber in October. Due to the limited project and growing period only preliminary conclusions can be drawn. The improved greenhouses showed a 3° higher night temperatures in April due to passive heating, the climate in summer and autumn was similar to the traditional greenhouses. The tomato production in the improved tunnels was 40% higher, mainly due to improved pollination. The effects on water use efficiency could not be demonstrated yet due to technical problems.

Keywords: greenhouses, water use efficiency, passive heating, tomato, cucumber, Lebanon

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Preface

The Syrian crisis has had serious consequences for Lebanon. More than 1.5 million refugees have found refuge in the country. Meanwhile, the Bekaa Valley, to the east of Lebanon, is experiencing a shortage of drinking water and sanitary facilities. Local agriculture is also suffering from drought conditions. In these challenging circumstances, however, it is of crucial importance that the region be able to achieve good harvests, provide employment and grow its economy. World Waternet, Acacia Water and Wageningen University & Research worked together to support Lebanon using Dutch water and agricultural expertise. This project was funded by the Dutch Ministry of Foreign Affairs. In this report the results of the Greenhouse component are described.

We like to thank the Lebanese Agricultural Research Institute to host the construction of demo greenhouses on their premises and to carry out the cultivation. We furthermore like to thank Robinson Agri for their support and commitment to realize the greenhouses and Rijk Zwaan for providing seeds.

Summary

Water use efficiency in open field crops is very low compared to greenhouse cultivation. Accordingly, the use of greenhouse technology is an interesting option for (semi-)arid countries to decrease water use while maintaining or even increasing food production, and improving livelihood and labour opportunities. Within this component a demo centre has been set up in the Bekaa Valley, Lebanon. The demo centre will be used to show the advantages of the use of modern horticultural techniques, which are affordable and suitable for local growers, like soilless cultivation, reduced water use, optimal nutrition, ventilation/cooling compared to the traditional greenhouses. The demo centre plays a key role in the educational and extension program aimed at reaching a broad group of farmers anon.

After a thorough investigation, a location was selected at the premises of the Lebanese Agricultural Research Institute (LARI). On this location two traditional greenhouse and two specifically designed, so called adaptive, greenhouses were constructed. An adaptive greenhouse is a greenhouse that is specifically designed for and aligned to the local conditions. The adaptive greenhouse concept incorporates:
- Sector assessment in terms of market analysis en prices;
- Development of business plan;
- Location specific data (climate, resources, legislation);
- Design and development of greenhouses;
- Design and development of cultivation systems;
- Collaboration with knowledge and dissemination networks.

The design of an adaptive greenhouse is an essential step in the successful improvement and expansion of greenhouses in Lebanon.

The main tasks of this component were:
1. To construct greenhouses at one location according to the adaptive greenhouse concept;
2. To set up a cultivation of vegetables and analyse the pilot in terms of yield and quality, water use and economic feasibility;
3. To disseminate practices to interested farmers.

A locally affordable and efficient greenhouse has been designed based on computer simulations using local climate data (Van Os *et al.* 2019). Two improved (adaptive) greenhouses and two traditional tunnels have been constructed in the Bekaa Valley. Cultivation is both in soil and in substrate, thus showing several steps in innovation.

The main innovations are:
- Ventilation and insect netting in side walls;
- Substrate;
- Fertigation computer;
- Passive heating;
- Irrigations sensors;
- Rainwater collection;
- High wire cultivation.

Construction of the greenhouses started in December 2017 and the greenhouses were delivered in March 2018. The construction of structure went swiftly but the realisation of the more novel aspects like irrigation and fertigation systems took much time. Some technical issues have still not been solved completely and hampered the registration of climate data and water use.

Cultivation started in April 2018 with tomatoes followed by cucumber in October. Two zones were planted later because of the lack of substrate. There were numerous complications with the irrigation/ fertigation at the start of the experiments due to both technical problems and the lack of experience. As a result the amount of water and the composition of the fertilizer solution were not always optimal leading to suboptimal growth. Harvest of the tomatoes started at the end of June and lasted until mid-September. At that time the cultivation was stopped because of the damage resulting from *Tuta absoluta* despite the pest control.

These yield data show that:

- Improved tunnel has a 30% higher yield than the traditional tunnel because of a much higher average fruit weight;
- Difference in yield between Soilless and Soil is close to 40%, again the average fruit weight is quite different, but also the non-controlled vegetative growth in soil is reason for a lower yield;
- The quality of the tomatoes in soilless tunnels was much better (91%) compared to soil (68%). A smaller difference can be seen between the improved and traditional tunnels.

In a normal year the above mentioned production level could rise up to 10-15 kg/m^2. With increasing knowledge and controlling equipment about 20-25 kg/m^2 is affordable in coming years.

Cucumber was planted early October and cultivation continued to the beginning of January when temperatures dropped to 4°C outside temperature and greenhouses were covered with snow. From the end of October onwards temperatures were low resulting in a very slow growth (10-20 cm) in the first month. The first harvest was in the beginning of December, approximately 2 weeks later than expected. The differences in yield between the treatments was small: yield from the improved tunnel in soil and from traditional tunnel with soilless cultivation were somewhat higher than the other treatments. Difference were not as pronounced as for tomatoes, probably due to the limiting climate conditions. Non marketable fruit was about 10%; 2nd quality was somewhat high, mainly caused by the non-favourable cucumber climate.

We did not succeed in acquiring accurate data on water use for either the tomato or cucumber cultivation. The greenhouses were constructed with 14 water meters (8 for supply, 4 for drainage and 2 for rain water). However, only the water supply meters worked properly. In soilless and soil production 93 and 103 L/kg was used for the cultivation of tomatoes. Irrigation strategy were the same for the traditional tunnel and the improved tunnel and could not be optimised yet as drain measurements were lacking. For cucumber data were respectively 100 – 166 L/kg for soilless and 135 – 170 L/kg for soil. The realised water use efficiency is far below the potential efficiency as water use could not be optimised yet on the radiation, registered drain or soil water sensors.

1 Introduction

Water use efficiency in open field crops is very low compared to greenhouse cultivation (van Kooten *et al.* 2008). Accordingly, the use of greenhouse technology in an interesting option for arid countries to decrease water use while maintaining or even increasing food production, and improving livelihood and labour opportunities. Within this component a demo centre has been set up in the Bekaa Valley, Lebanon. The demo centre will be used to show the advantages of the use of modern horticultural techniques like soilless cultivation, recirculation of water, optimal nutrition, climate control, ventilation/cooling, high wire cultivation and others compared to the traditional greenhouses. The demo centre plays a key role in the educational and extension program aimed at reaching a broad group of farmers in Lebanon.

After a thorough investigation, a location was selected at the premises of the Lebanese Agricultural Research Institute (LARI, Figure 1) in the Bekaa Valley. Several other locations both at commercial parties and with LARI were visited to make a selection of potential sites. A site at LARI was preferred to avoid any commercial bias and to have the advantage of a research environment being more used to measurements and experimental work. Moreover, we hoped that the setting at a research station would guarantee a more sustainable situation for the demo centre after the end of the project. LARI has sites at Tal Amara, Abadeh, Kfarshakhna, Fanar and Tyre. The site in Tal Amara was most attractive because of the availability of land, labour and safety situation (not being in a red zone). On this location two traditional greenhouse and two specifically designed so called adaptive greenhouses were constructed. An adaptive greenhouse is a greenhouse that is specifically designed and aligned to the local conditions. The adaptive greenhouse concept incorporates:

- Sector assessment;
- Development of business plan;
- Integration with the supply chain and market concepts;
- Design and development of greenhouses;
- Design and development of cultivation systems;
- Collaboration with knowledge and dissemination networks.

The design of an adaptive greenhouse is an essential step in the successful introduction and expansion of the greenhouse area in Lebanon

Figure 1 *Map of LARI locations in Lebanon (left) and growers visiting the site (right).*

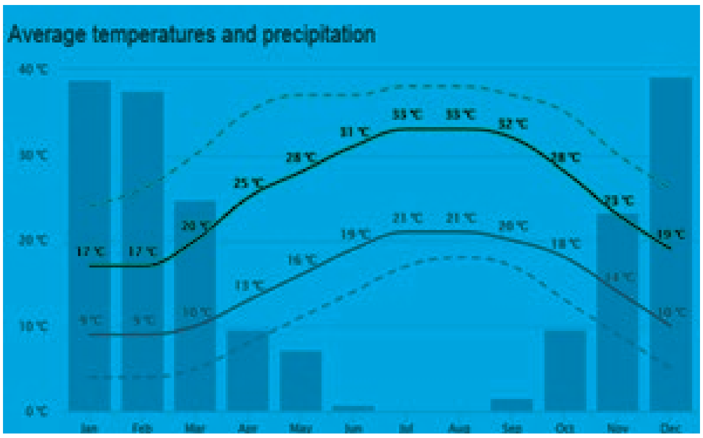
2 Greenhouse design

2.1 Climate

To benefit completely from the potential advantages of a greenhouse, local conditions have to be taken into account. The local climate is of importance. Looking to the map (Figure 2) there is a narrow coastal area with Beirut, but also with numerous single tunnels on the slopes of the first mountain range. Between the Lebanon and the Anti-Lebanon mountains there is the Bekaa Valley, for centuries an agricultural area with a predominant cultivation of wheat, potatoes and other grains and for instance grapes. More and more other crops (tomato, cucumber, sweet pepper and lettuce) are produced in this area. Protection against rough weather is recommended and more and more greenhouses are built to grow these crops.

Figure 2 Map of Lebanon, left, and an overview of the Bekaa valley, right.

To design a good greenhouse construction it is good to know the climate: wind, rain, heat, cold, snow. With KASPRO, based on first studies of De Zwart (1996), a model approach can take place to investigate what greenhouse is needed in the given climate (Figure 3). For the model a data file is needed with at least a 2 h intervals, but preferably 5 minute. There were not that many datasets available. Finally the climate dataset from 2015 (Tal Amara) was used as input to the KASPRO model.



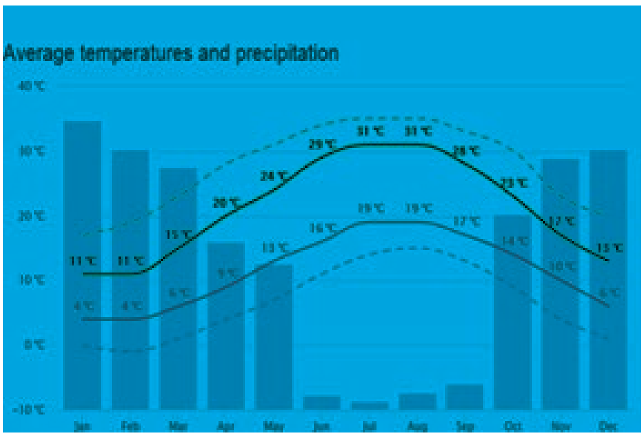


Figure 3 Average climate data in Beirut (left) and Bekaa Valley (right).

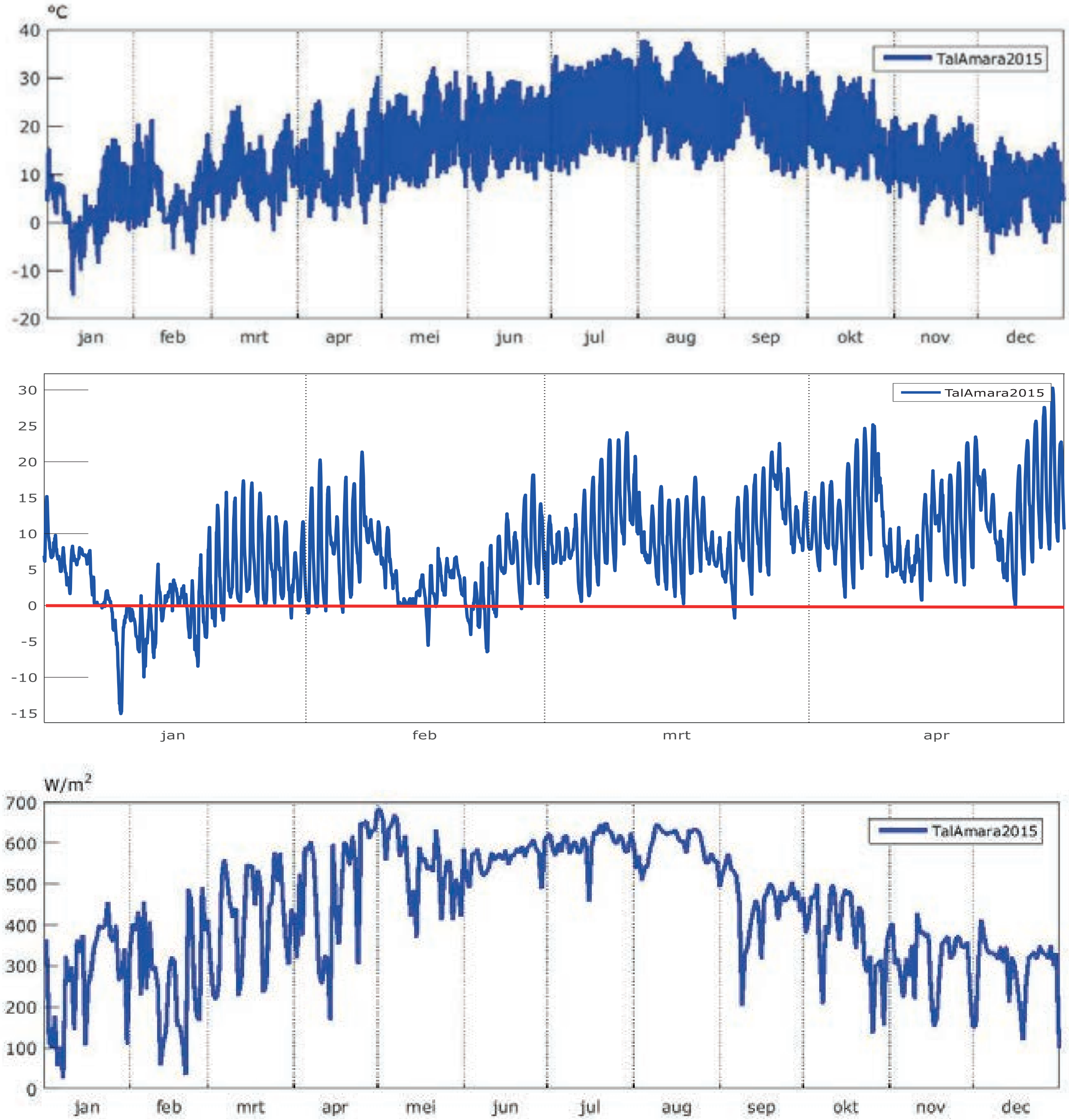


Figure 4 *Model input of the weather data (temperature) for 2015 in the Bekaa for the entire year (above) and for a few months (middle) and the solar radiation (below).*

It became clear that Spring and Autumn in the Bekaa are colder (than along the coast) (Figure 4) and the winter is even much colder with temperatures around or just below zero and chance for snow. The latter is also the reason why the cultivation season in general dates from half of April to November. In winter often lettuce is grown, but no more tomato or cucumber.

It can be seen that radiation in Tal Amara is relative high in winter and spring, along the coast clouds often decrease the radiation. Similar Figures were made for relative humidity (RH; low RH in Bekaa) and wind speed (sometimes strong winds in Tal Amara).

2.2 Present local greenhouses

The mostly used greenhouses in Lebanon are single tunnels of 8m wide and 41.5m long and about 3m high (Figure 5). Ventilation is limited to the doors in front and rear (6x2m) realizing less than 10% ventilation vent area/ground ratio. Sometimes small squares are made in the side walls, but they have only a limited effect (about 2% additional ventilation). The microclimate oscillates very much because of the small volume above the crop. Due to the high altitude (900m), day and night temperatures and RH vary dramatically, so the climate for the plants is probably not optimal. The challenge is to design an economic affordable tunnel, with more ventilation.

Figure 5 *Local tunnels in the Bekaa valley.*

Figure 6 *Alternative greenhouse designs to be investigated.*

Alternative greenhouses may have sidewall ventilation as a solution for the high temperatures inside (Figure 6), a multispan construction too. At the other hand there might be a need for screening (white-washing against summer sun) or a fixed thermal plastic screen and/or water filled sleeves (against cold in winter), rainwater collection or insect screening. These types of solutions were compared with the traditional tunnel in KASPRO and described in the paragraphs below.

2.3 Simulation of optimal greenhouse design

Side wall ventilation
Side wall ventilation (automated) is the first step to climate control because sidewalls close if temperature drops below a certain value and opens above a certain set-point. There is better control of temperature, reason to use less white wash with the consequence that more light is coming in (influence on yield) and temperatures at hot days rise a bit more as in the traditional tunnel (Figure 7). In winter the larger air buffer in the side wall ventilated tunnel creates higher temperatures. During the night RH is in a traditional tunnel higher (close to 90-100%) as in the side wall ventilated one, especially in summer and autumn.

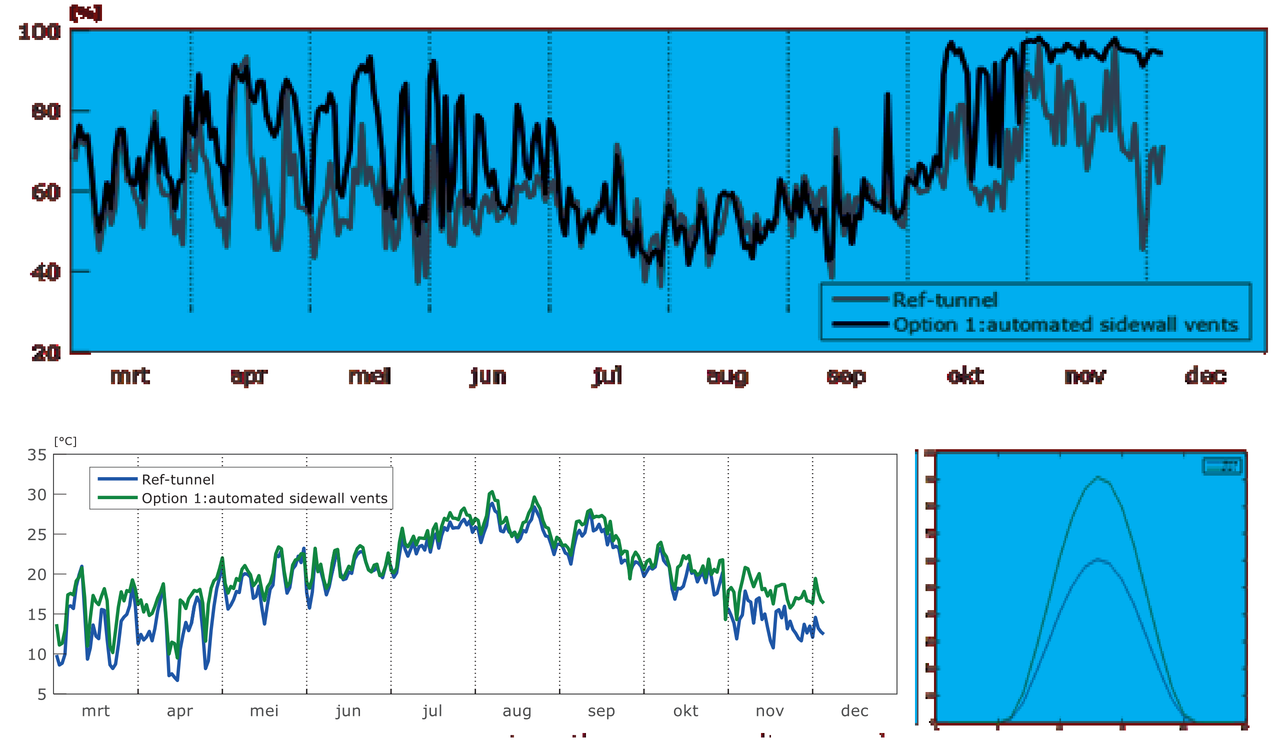


Figure 7 *Diurnal mean RH (above)) temperatures (below; left) and radiation (right; blue is reference, red is Option 1) during the year.*

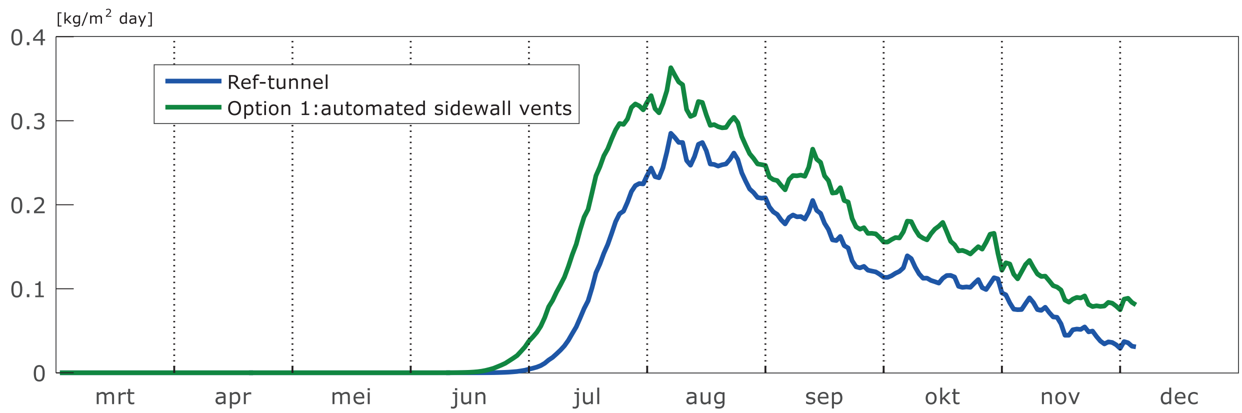


Figure 8 *Total yield in reference tunnel and side wall ventilated tunnel during the year.*

The yield in the side wall ventilated tunnel is higher due to more light (Figure 8). An increase from about 21 kg/m^2 to 29 kg/m^2 looks like a realistic option.
Concluding: a controllable side wall ventilated tunnel can perform better because of more light in the tunnel and lower RH on average. Temperatures are similar compared to the reference tunnel.

However in early spring it is too cold outside for optimal growth. Investing in heating equipment is too expensive, but are there other solutions? In Spain there is some experience with a fixed plastic film during the first weeks in the top of the tunnel and with water filled sleeves (water contents of at least 50 L/m^2, no shadow of plants; Baeza *et al.* 2017). The latter collects the radiation during the day and temperature of the water increases, which is released into the air during the night.

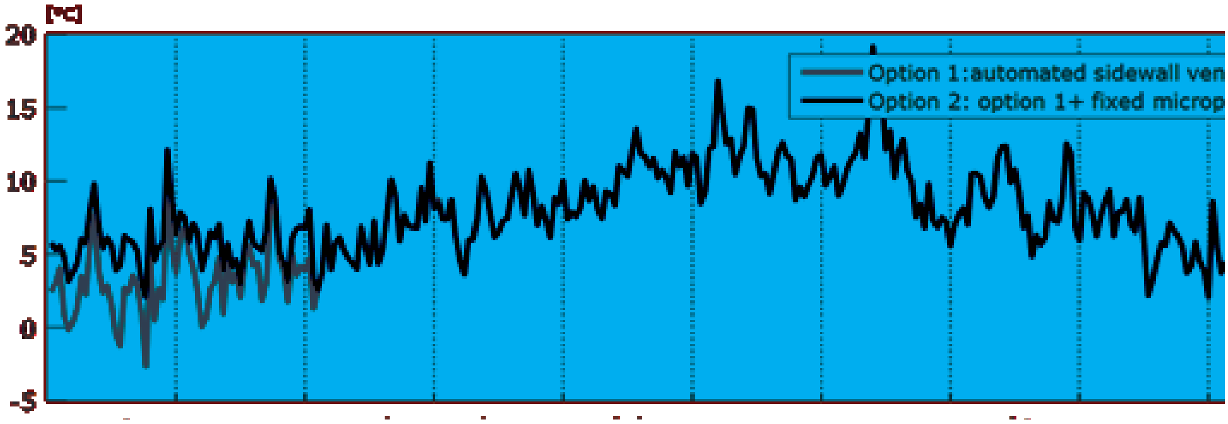


Figure 9 *Effect of fixed polyethylene film in top of the greenhouse during early spring.*

A fixed polyethylene liner in top of the greenhouse is an additional option (Figure 9). Yield increase is only 1 kg/m^2 compared to the side wall ventilated tunnel. However it also prevents condensation water to fall on the crop (less risk on fungi) and less risk on frost. So it might be possible to start a few weeks earlier in the season. Having the water filled sleeves (realizing 25 W/m^2, comparable with 13 m^3 natural gas per m^2) the night temperature can be slightly increased during the whole year but especially during early spring when the crop is very low (0-50cm) and the sleeves receive enough radiation. Because of the higher temperature yield may increase up to 30 kg/m^2.

Bi-tunnel compared to traditional tunnel

The idea to use a Bi-tunnel (2 spans, one space; Figure 6, right) is to create a uniform climate in a larger space. There are less side walls bus still enough to cool. It appeared that the diurnal temperatures, RH and disease risk in the tunnels are similar. Yield is slightly higher (36 kg/m^2) in the Bi-tunnel because of less shadowing parts.

In table 1 the various options are summarised for yield effect.

Table 1

Yield effect of simulated scenario's compared to a traditional tunnel.

Greenhouse scenario	Yield (kg/m^2)	Relative (+%)
Reference tunnel	20.8	100
Option 1, automated side wall ventilation	29.6	142
Option 2, option 1 + fixed perforated film in first two months	30.6	147
Option 3, option 2 + passive heating	35.0	168
Bitunnel	35.7	170

2.4 Conclusions and recommendations tunnel design

From the KASPRO calculations described above the following conclusions can be drawn:

- A single tunnel (41.5 x 8 m) or a Bi-tunnel (41.5 x 8 m) with two rolling sidewall ventilation of at least 1.5 m height and an anti-aphids netting will be compared with a traditional tunnel
- A highly transparent thin perforated film will be used during the first months in early spring to prevent condensation drops to fall on the crop and to increase the night temperature.
- A passive heating system of 6 water filled sleeves (>50 L/m^2) per tunnel can be used.
- A whitewash with 40% shading during the summer months to achieve more 1st quality fruits. BER might also be prevented with a lower transpiration rate as well as fruit damage by sun burn.

2.5 Rainwater collection

Water is rather scarce in Lebanon and groundwater levels are continuously decreasing due to over exploration. Water saving is therefore of utmost importance. Collection of rain water from the greenhouse would be of help to reduce the water use of horticulture

Well water is used in Tal Amara at the moment. The quality is reasonable for cultivation. The high pH caused by a high (4 mmol/l) HCO_3^- concentration has to be taken into account when using fertigation (Annex 1). In summer complete neutralising is difficult because it needs time which is not available: frequent filling of the mixing tank is needed, consequently the pH is not dropped sufficiently. Therefore, the bicarbonate has to be neutralised, preferably, before the nutrient solution is prepared in a separate tank to give it its time. In other regions river water is used which has a good quality in spring when there is abundant water, but quality decreases dramatically during the summer season.

The collection of rainwater via gutters is easy (Figure 10), but traditional tunnels don't have gutters. although during the orientation visits it appeared that hardly anybody collects rainwater even if the greenhouse is suitable for it. For this demo we thus selected a greenhouse type at which gutters could be placed.

A new development is the collection of rainwater from traditional tunnels (Figure 10). For this the space between tunnels was covered with a thick (0.5mm) liner filled up with an inert gravel type of coarse grading (at least >8mm). The use of coarse gravel between the tunnels has more advantages: the area becomes less humid, no plants/weeds will grow and no insects or fungi can live there which decreases the disease pressure in the greenhouse itself.

Figure 10 *Schematic view on rainwater collection from a greenhouse with gutters (left) and from traditional tunnels (right).*

2.6 Final design and construction

Based on our analysis and discussions with local partners (LARI, Robinson, Daccache, Debbane, FAO, Green Plan) the following design was chosen and described in detail in the terms of reference (TOR):

- Two traditional tunnels, one with cultivation in soil and one in coir (coconut fibres);
  - Drip irrigation as normally used (4 L/h non-pressure compensated) for soil and pressure compensated drippers (2L/h) for soilless cultivation.
- Two improved (chapel type) tunnels, one with cultivation in soil and one in coir (coconut fibres);
  - Controllable side wall ventilation and insect netting over at least 1.5 m;
  - High wire cultivation system including hooks, strings and a trolley;
  - Use of bumble bees for pollination;
  - Entrance sluice;
  - Drip irrigation as in use normally (4 L/h non-pressure compensated) for soil and pressure compensated drippers (2L/h) for soilless.

- Fertigation/climate computer suitable for soil and soilless cultivation and recirculation and having an internet connection to send data to WUR directly;
  - Including a weather station;
  - For four tunnels and in each tunnel two irrigation zones (8 measuring boxes);
  - A, B and acid storage tanks.
- Water counters for supply (8, one of for each irrigation zone) and returning drainwater (4, one for each irrigation zone in soilless cultivation) and rainwater (2, one for improved and one for traditional tunnels);
- Collection of rainwater from the tunnels and storage in tanks/basins;
- Passive heating via water filled sleeves and fixed perforated film.

LARI would do the levelling of the soil, make electricity and water available. They also placed a control room where the fertigation unit and computer could be placed and includes a small office.

A constructor was selected based on tendering. Based on the offers Robinson Agri was selected. They started construction in December 2017. Delivery took place in March 2018 (Figure 11) and by mid-April plants were planted in the four tunnels. In Annex 2 an overview of the construction process is given. During the visit at the end of February 2018 details about construction and installation were discussed. It appeared that constructing these innovative greenhouse compartments for research was something different as constructing traditional tunnels. For Robinson Agri many topics had to be explained. The fertigation unit of Hoogendoorn could also be installed but testing could not yet take place because of lack of water connections. Later this appeared to be a serious issue in the malfunctioning of the installation.

A schematic overview of the installations is given in Figure 12.

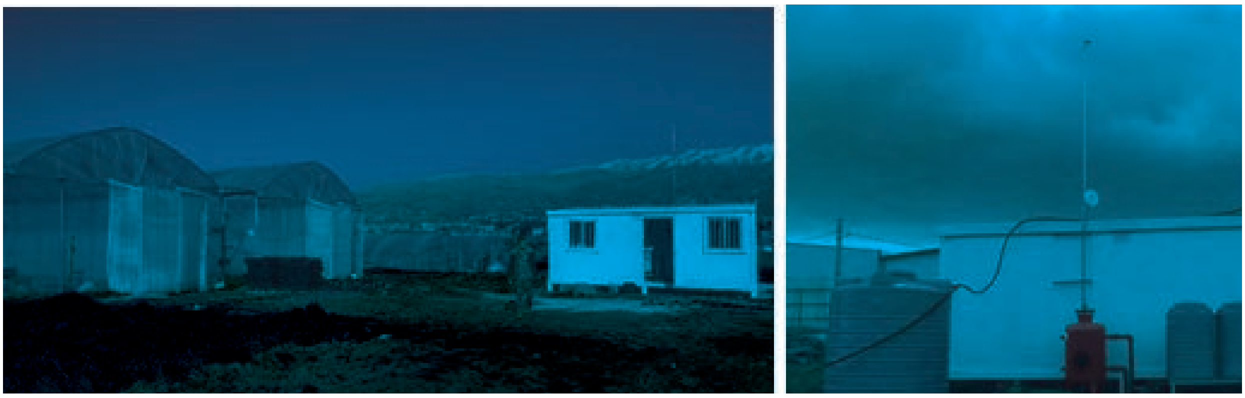


Figure 11 *Left two improved tunnels, middle two traditional tunnels, right the control room with equipment. Right picture the back side of the control room with water storage, filter, concentrated fertilizer tanks, weather station and water use counters.*

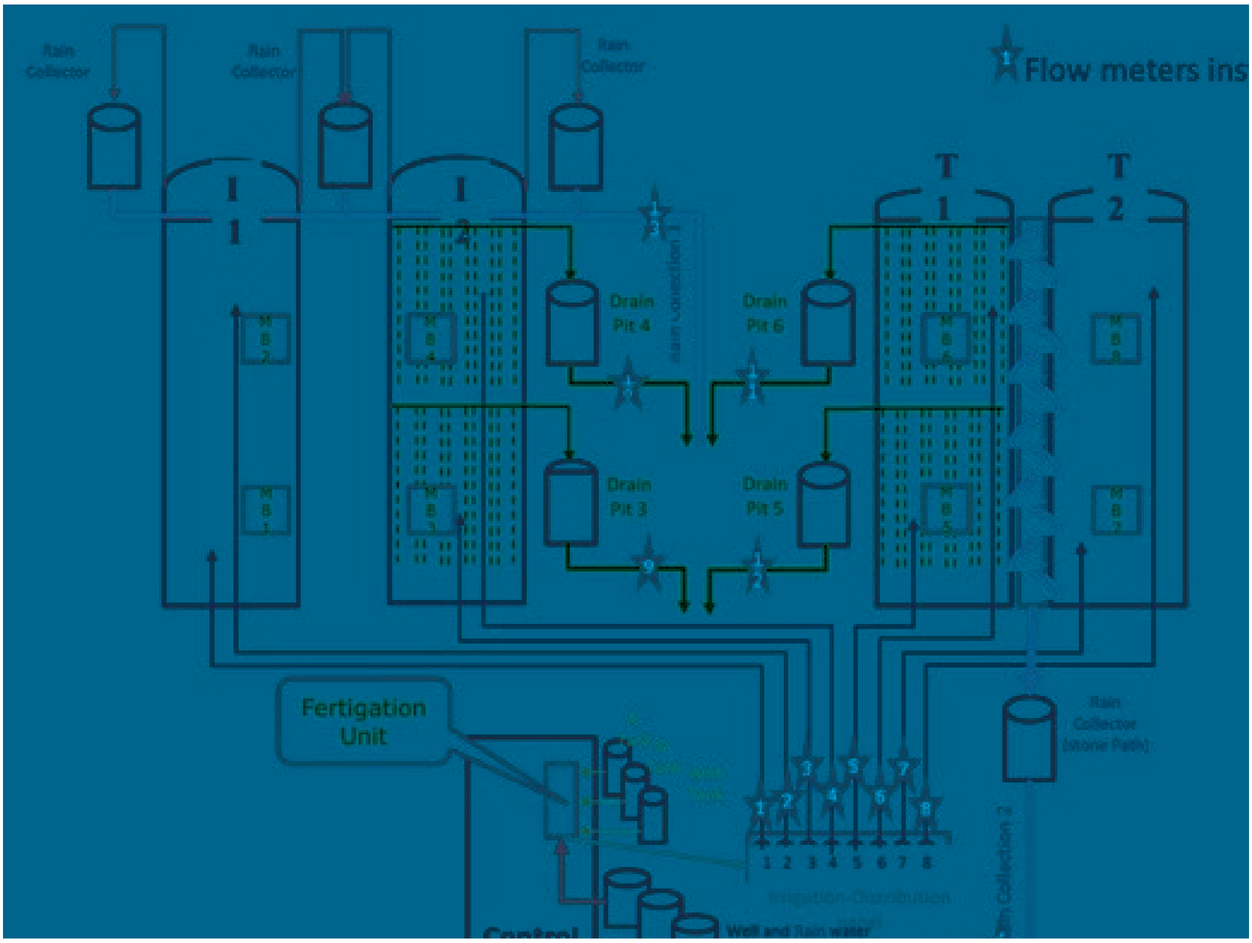


__Figure 12__ Schematic overview of the greenhouse installation.

3 Cultivation of tomato

3.1 Realized climate

Light transmission
At two moments light transmission of the tunnels was measured; once in March and once in July (Figure 13 and 14). It was measured with two calibrated sensors, one placed outside and one was moved through 4 lines in the tunnel and compared with the outside one, resulting in relative light transmission.

Figure 13 *Same tunnel in March (left) and July (middle) and method of measuring (right).*

Between tunnels there is not much difference in light transmission (Figure 14), but it is clear that there is a big difference in light transmission between March (new plastic) and July (during the dusty summer).

Realized climate in the tunnels
Climate data were collected from outside weather station (upon roof of control room) and via 8 measuring boxes in the 4 tunnels (Figure 15). Via Let’s Grow (dbase) data were translated in an excel overview file which could be monitored continuously and was updated daily.

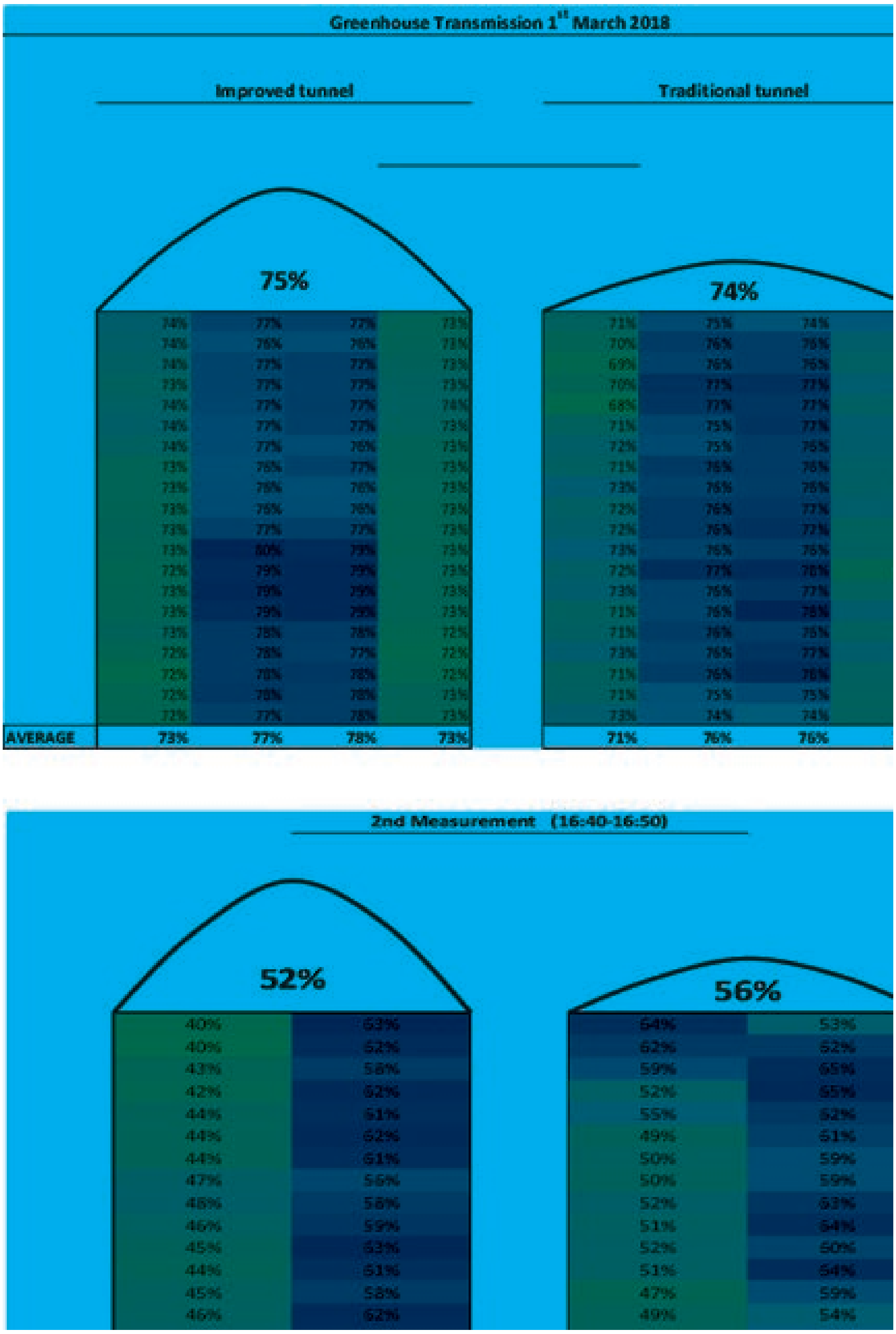


Figure 14 *Light transmission measurements in March (above) and July (below). Left Figure of each date is the Improved tunnel, traditional tunnel on the right.*

Figure 15 *Measuring box in tunnel (left), placing of weather station (middle), measuring sensors on mast on control room (right).*

The outside weather is presented in Figure 16. Most extreme was a short hot period around June 9, further the outside weather was not extreme, looking to the temperatures. Daily radiation is high compared to the Netherlands. Up till June some cloudy weather can be seen. Here after the weather is mainly sunny till end of cultivation of the tomatoes in September.

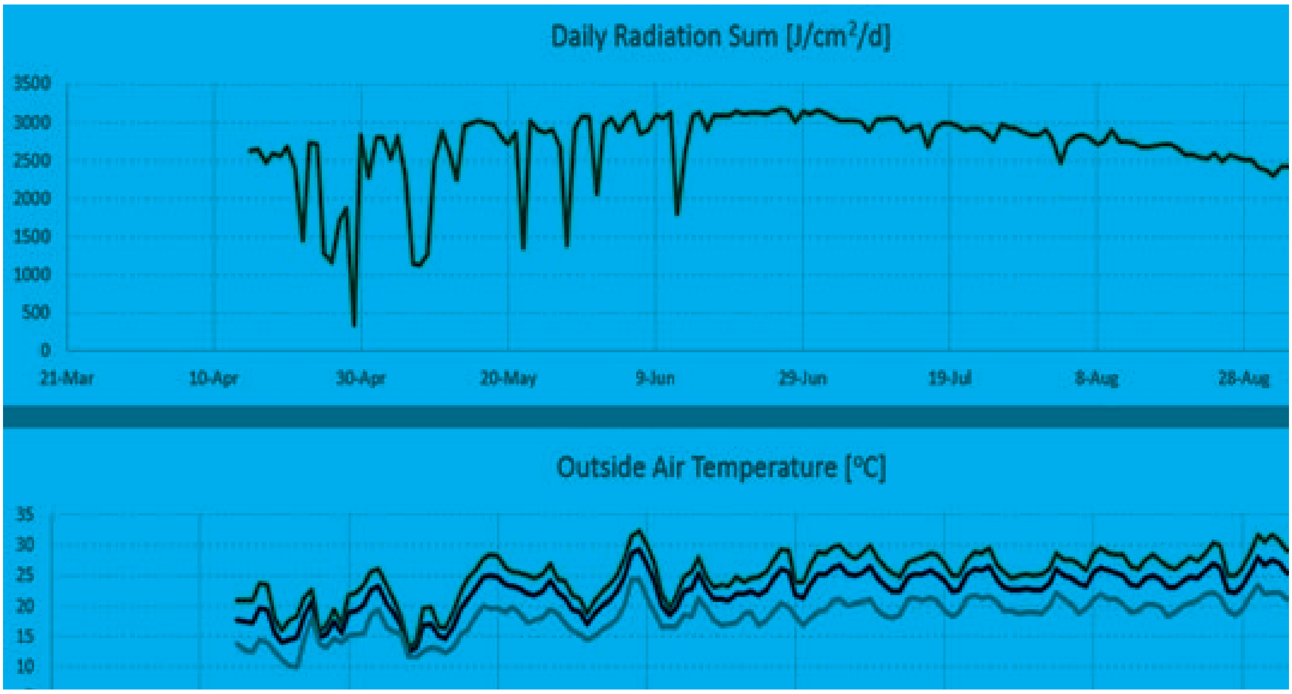


Figure 16 *Outside weather characterised in daily radiation and temperature (orange is max, green is average and grey is minimum temperature).*

In Figure 17 a comparison was made between the temperature and RH inside the 4 tunnels. The data for April are difficult to interpret as experience has to be gained to get the right set-points (opening and closing times of the side walls) and staff had to be instructed (closing the doors in the improved tunnels). In May the RH in soil tunnels is higher, partly caused by an abundant irrigation in April (see Figure 20). The vegetative growth (more leaves, more transpiration) resulted in lower temperatures in soil in May and early June. Later in summer the improved soil tunnels showed some higher temperatures which could not be explained. In general data of T and RH 24h time and during night time showed differences of less than 1°C between tunnels.

Passive heating
During construction a fixed plastic film and passive heating (water filled sleeves) were installed (Figure 18). As plants came in in April it became too hot soon. Early May plastic film is removed and a few days later the water filled sleeves were removed. At some cold nights (16-18 April) a temperature difference of 3°C could be achieved between improved and traditional tunnels.

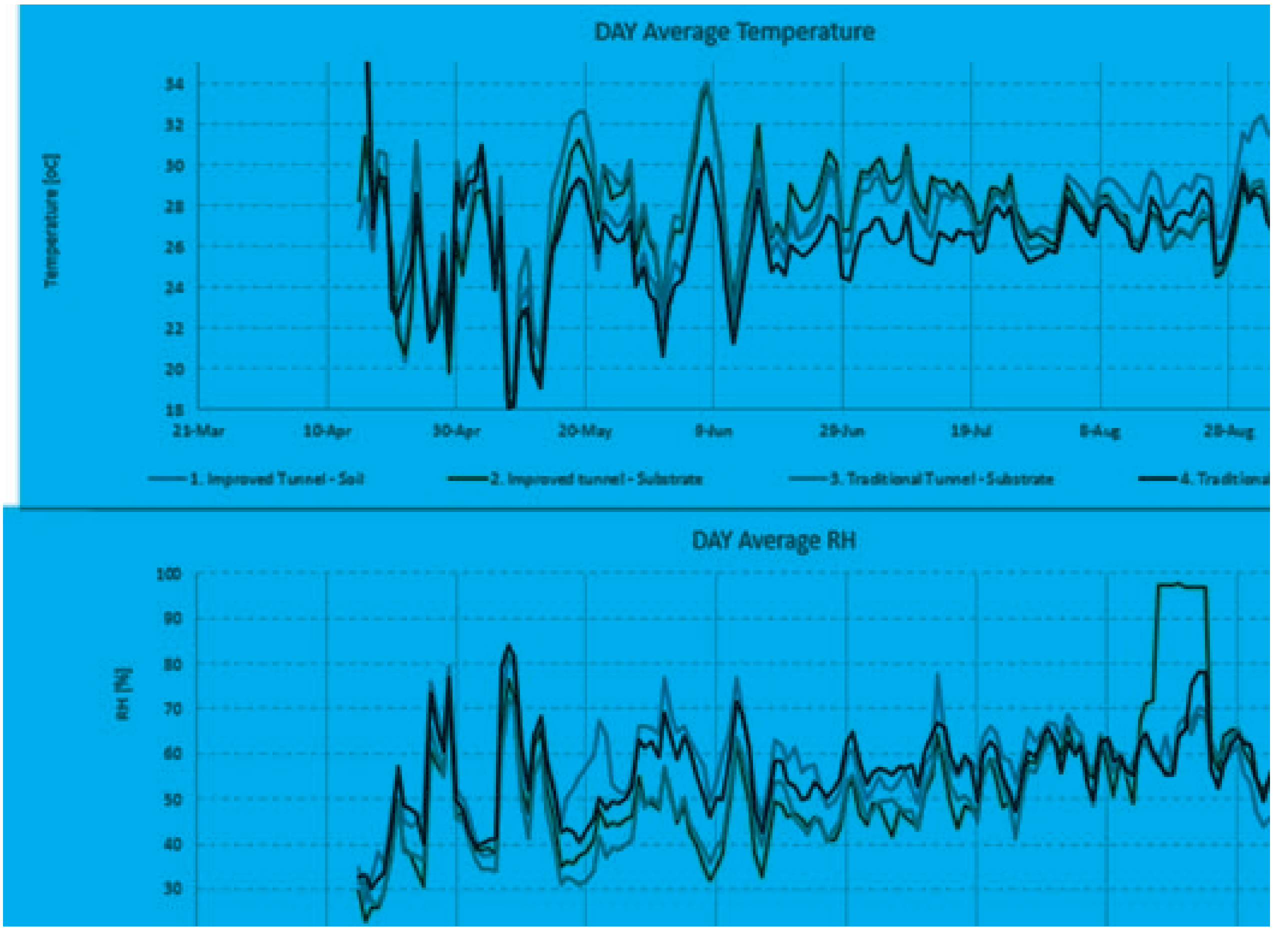


Figure 17 *Inside average Day temperature and Day RH; (high RH peak in Improved tunnel substrate is caused by an empty measuring box).*

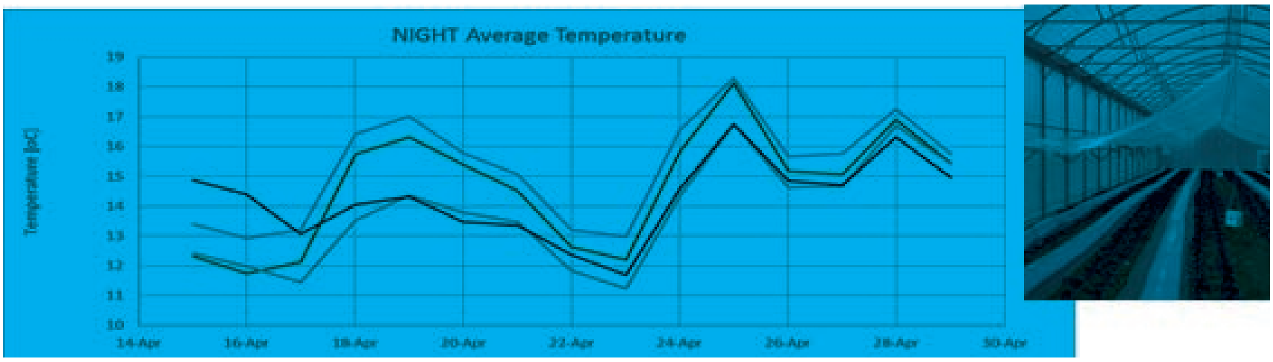


Figure 18 *Passive heating applied in the improved tunnels and realized temperatures in April.*

3.2 Irrigation and water use

It was the idea to realize an optimal irrigation strategy by measuring both the supplied water and the drainwater form the tunnels with soilless cultivation. The differences between both terms gives an estimate of the uptake of water by the plants. Based on these data the irrigation strategy for the soil cultivation could be detected. Therefore all 12 water meters should be readable from the computer. However only 8 water meters, measuring the supply, functioned well and were daily manually read. The computer could collect data about the frequency of irrigation, by calculating the amount of drippers per tunnel the supplied quantity of water could be estimated (Annex 1). A few times the estimated supply by drippers was compared to the data of the water meters. In Figure 19 an overview of supplied irrigation water is given (number of shots was registered by the computer).

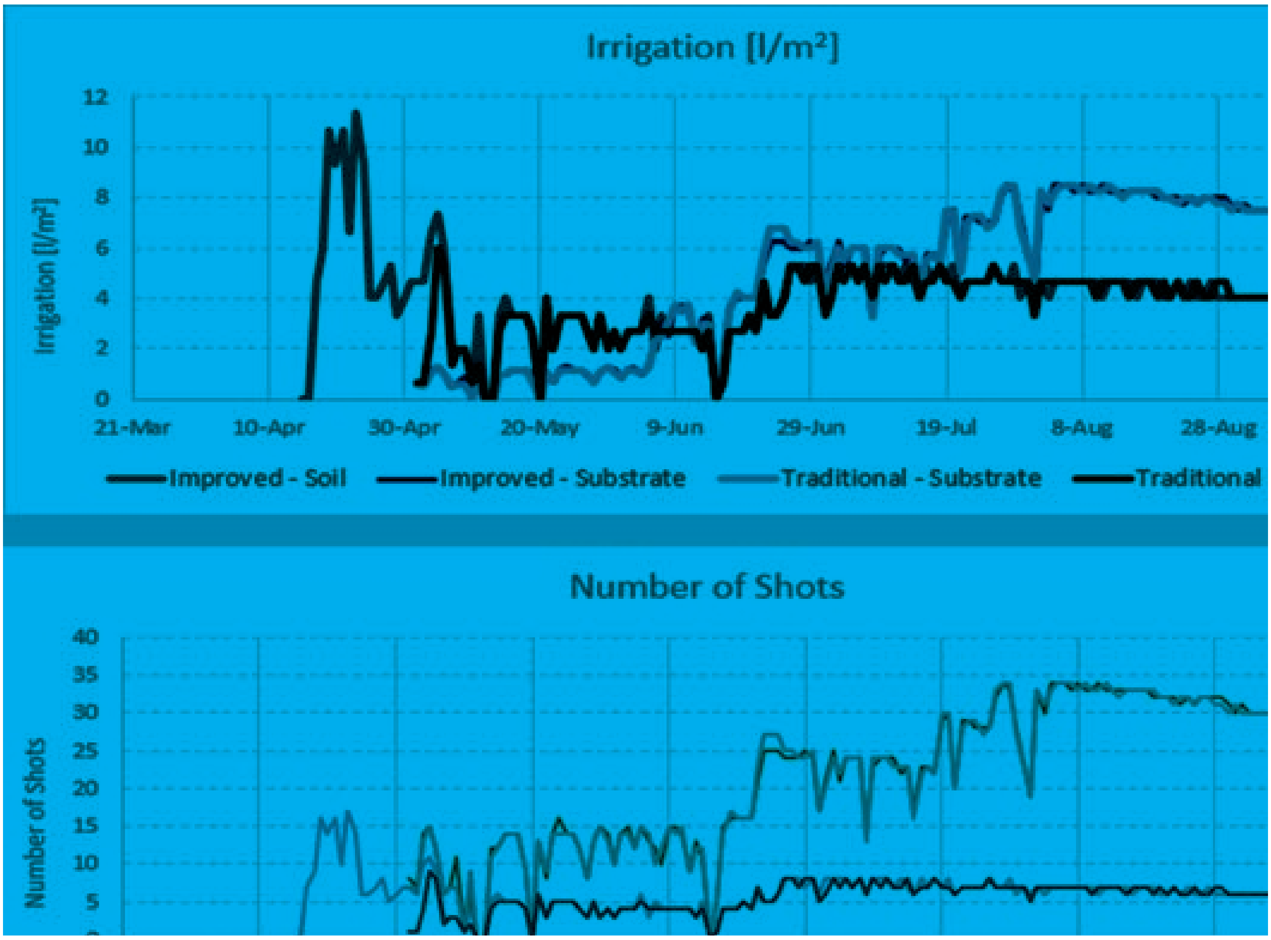


Figure 19 *Realized irrigation per tunnel (number of shots, lower graph) and estimated amount (L/m², upper graph).*

The frequency of irrigation in soilless and in soil tunnels was the same in April. However the drippers in soil were 4 L/h at 25 cm interval (as normal in Lebanese cultivation), while in soilless there were 2 L/h drippers at 50 cm interval. As drainwater measurement was not functioning (too big pump in a too small tank) there was no good information about the amount of drain and the realised water uptake by the plants. Measurements showed that only 75% of the calculated amount reached the plants in the soilless cultivation and that the coming off of nozzles altogether realized a smaller supply to the plants than indicated by the water meters/computer. This resulted in a too generative growth on soilless cultivation, while the abundant irrigation in soil realized a very vegetative growth (to be discussed in chapter Cultivation). After half of June these set points of irrigation were improved.

The water supply (and no recirculation) in the 4 tunnels was rather constant and not optimised. The calculated water use (L/kg fresh produce) is only indicative. In soilless and soil production 93 and 103 L/kg was used). If these Figures are compared with the literature data (Figure 20, Van Kooten *et al.* 2008) there is still a long way to go. In a next crop it should be possible to decrease the amount of water used to about 30-40 L/kg. With use of the drain measurements and adaptation of the supply, the use of rainwater and better understanding about growth and irrigation it should be possible.

Climate and growing system	Tomato	Sweet pepper	Cuc
Open field production	60 (Israel)	300 (Spain)	600 (
Spain, unheated plastic "parral"	40		
Israel, unheated glass	30		
Spain, unheated "parral", regulated ventilation	27	74	
Holland, climate-controlled glass, CO_2 enrichment	22		
Holland, as above, with re-use of drain water	15	22.8	

Figure 20 *Amount of irrigation water required to produce 1 kg of fresh marketable produce in several climates and growing systems (Van Kooten et al. 2008).*

3.3 Start of tomato

Tomato plants (var. Valouro RZ) were raised at Robinson Agri (sown at March 25), planted at April 19 (6 zones) and April 30 (zone 3; no substrate available). Last zone (no. 5) was planted May 12 (no plants available anymore).
Irrigation started with many complications (too low pH, nozzles came off the tubes, tubes came off main lateral, unclear how long and how much was irrigated, no drainwater or when it was there it did not return, no pumps in drain pit; acid dosing too frequently, no hand EC/pH meter, dosing plain water instead of nutrient solution; no refill of empty A and B tanks; no knowledge of Excel; electric power failures and restart of computer). Problems were partly due to a lack of knowledge and partly due to initial malfunctioning of the technique. Both Hoogendoorn (via Helpdesk) and Robinson Agri were frequently consulted. Most problems could be solved or student staff (2 Master students, one on soil and one on soilless cultivation) could handle it. There was an internet connection to see in Wageningen if things were going fine; the What's app was often used to exchange information. Communication between all team members had to be optimised in the first period. It became clear that more intense labour was needed compared to traditional growth in tunnels without any options for regulation or registration.

Figure 21 *Soil improved, soil traditional; substrate traditional rear side, substrate improved front, substrate improved rear, substrate traditional front made at June 5.*

The result was an uneven crop (Figure 21), in soil the growth was too vegetative (too much water without fertilizer); in coir it was too generative (too little water, low pH, no drain control, no EC/pH measurement in substrate). Set-points were EC of 2.5, later 3.0 and pH 5.5. Later too low EC and too high pH in substrate (EC = 1.8, pH 6.3). Well water (EC 0.63, pH 7.7) was not well neutralised by the fertigation unit. A general overview of EC, pH and nutritional values is presented in Annex 1.
In both improved tunnels water filled sleeves and fixed film at top of tunnel were placed. Fixed film was removed at May 1, it was getting too hot and too humid. Sleeves were removed later in May.

3.4 Yield of tomato

Quantity
First yield was on June 25, 2018 and was continuously monitored to August 6 (table 2). All data were achieved from harvesting 20 plants per zone and harvesting 2x per week. Here after yield was poorly registered, just the total sum from the 4 tunnels up to September 11 when the cultivation was stopped because of *Tuta absoluta* was not controllable anymore. In coir we had to face several planting dates, reason why yield started uneven (Figure 22).

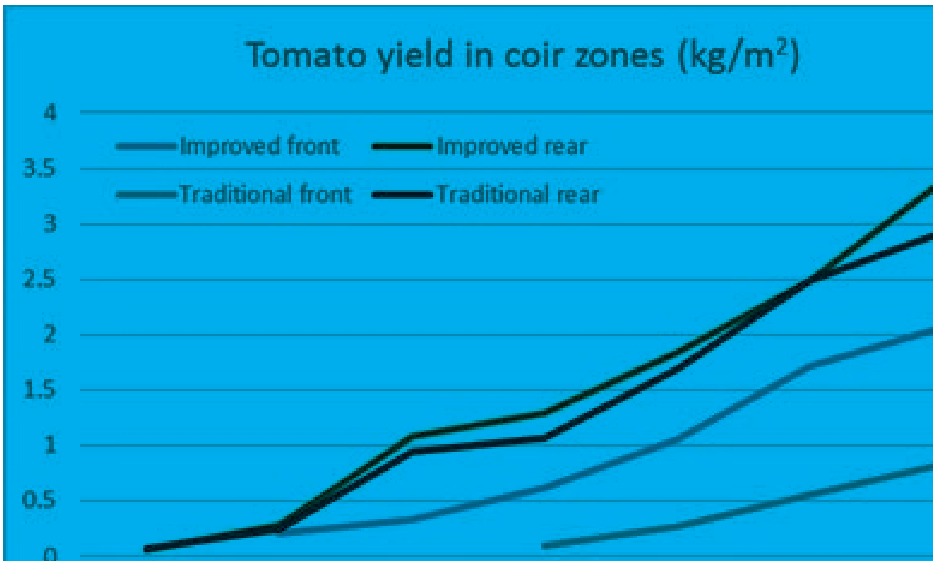


Figure 22 *Tomato yield from July 3 onwards in coir.*

Table 2
Final yield after 7 weeks harvesting.

Treatment	Zone	Yield (kg/m²)	Average fruit weight (g)	1st Quality (%)
Improved soil	1	2.6	121	68.6
	2	2.8	172	80.9
	Average	2.7	147	74
Improved soilless	3	2.1	175	88.3
	4	3.4	160	93.1
	Average*	3.4	167	93
Traditional soilless	5	0.8	148	44.5
	6	2.9	153	90.5
	Average*	2.9	150	91
Traditional soil	7	1.9	89	58.0
	8	1.8	86	66.1
	Average	1.9	87	62
Soil	Average	2.3	117	68
Soilless	Average	3.2	157	91
Improved tunnel	Average	2.9	151	83
Traditional tunnel	Average	2.2	109	77

**) Zone 3 and 5 are excluded from Average because of later planting date*

Although these are preliminary results over a short period which could be improved in a future cultivation some tendencies can be distinguished:

- Cultivation in two zones started later (zone 3 and 5) and are eliminated from average calculations;
- Improved tunnel has a 30% higher yield as Traditional tunnel because of a much higher average fruit weight (improved pollination);
- Difference between Soilless and Soil is even close to 40%, again the average fruit weight is quite different, but also the non-controlled vegetative growth in soil is reason for a lower yield.

Up to September 11 yield took place regularly.

Quality of fruit

For quality reasons harvested tomatoes were divided in 1st quality (>70g) and 2nd quality (non-marketable, <70g). From Table 2 it can be seen that the quality in soilless tunnels was much better (91%) compared to soil (68%). A smaller difference can be seen between the improved and traditional tunnels. Further the numbers of fruits with blossom end rot (BER), zippering, cracking were registered. Zippering (pollination problem) and BER (transpiration/fertilization problem) were limited to 3-5% of the fruits. Larger problem was cracking of the fruits. Especially in cultivation in soil in the traditional greenhouse where the soil was flooded once, because a drip line came off and the number of irrigation minutes was high for unknown reasons (plain water was given), here 70% of the fruits were cracked, after it decreased again. In other soil only 6% was cracked.

One special aspect is the pollination of flowers in the improved tunnels by bumble bees. It resulted in much bigger fruits of constant quality. One time random sampling of 20 fruits and counting the seed showed large differences between the improved greenhouse (fruit weight 112 g with 173 seeds per fruit) and traditional (81 g with 57 seeds per fruit) tunnels.

The yield and fruit weight in zone 3 was very low (table 2). The main reason is that the plants were just coming into flowering when there were some extreme hot days at which the bumblebees did not fly and no pollination took place.

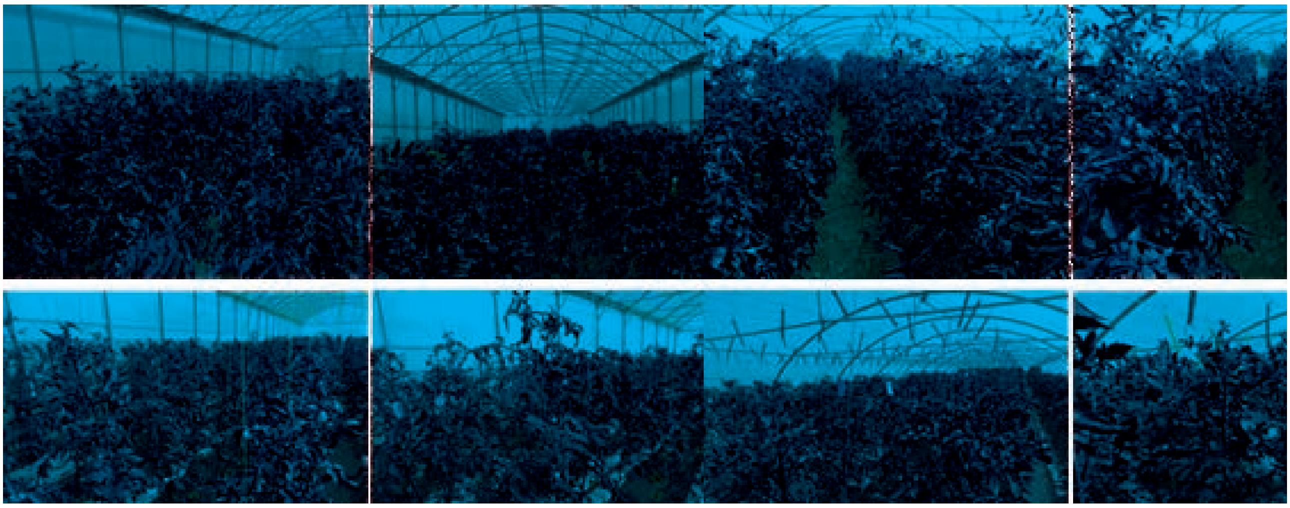


Figure 23 *Crop view at July 22, upper line: zone 1, 2, 7 and 8 (soil); lower line: zone 3, 4, 5 and 6 (soilless).*

4 Cultivation of cucumber

As the tomato crop was unexpectedly ended a new crop had to be selected for autumn. Tomato was not an alternative as plant raising and yield were coming too late in the season. Lettuce was, as crop, not suitable for soilless culture. Cucumber was the most suitable option as it comes quickly into production (within 3 weeks normally) and it was a real challenge for the region. Planting cucumber so late in the season is not done regularly as the temperatures will be too low.
After preparing the greenhouse the Rijk Zwaan cultivar Newsun was planted on October 12 2018 in new plant holes on the same slabs of coir and in soil. It was raised at the nursery of Robinson Agri and sown on September 24.

4.1 Realized climate

Looking to the outside climate (Figure 24) it can be clearly seen that temperatures in October were fairly high, but from the end of October onwards temperatures dropped below an average of 15°C and in December temperatures were around 10°C. Early January the trial was stopped as snow collected on the tunnels and temperatures were around 4°C. The weather change of early November could be seen clearly in the RH which was first rather low and summer oriented. Here after RH was around 80%.

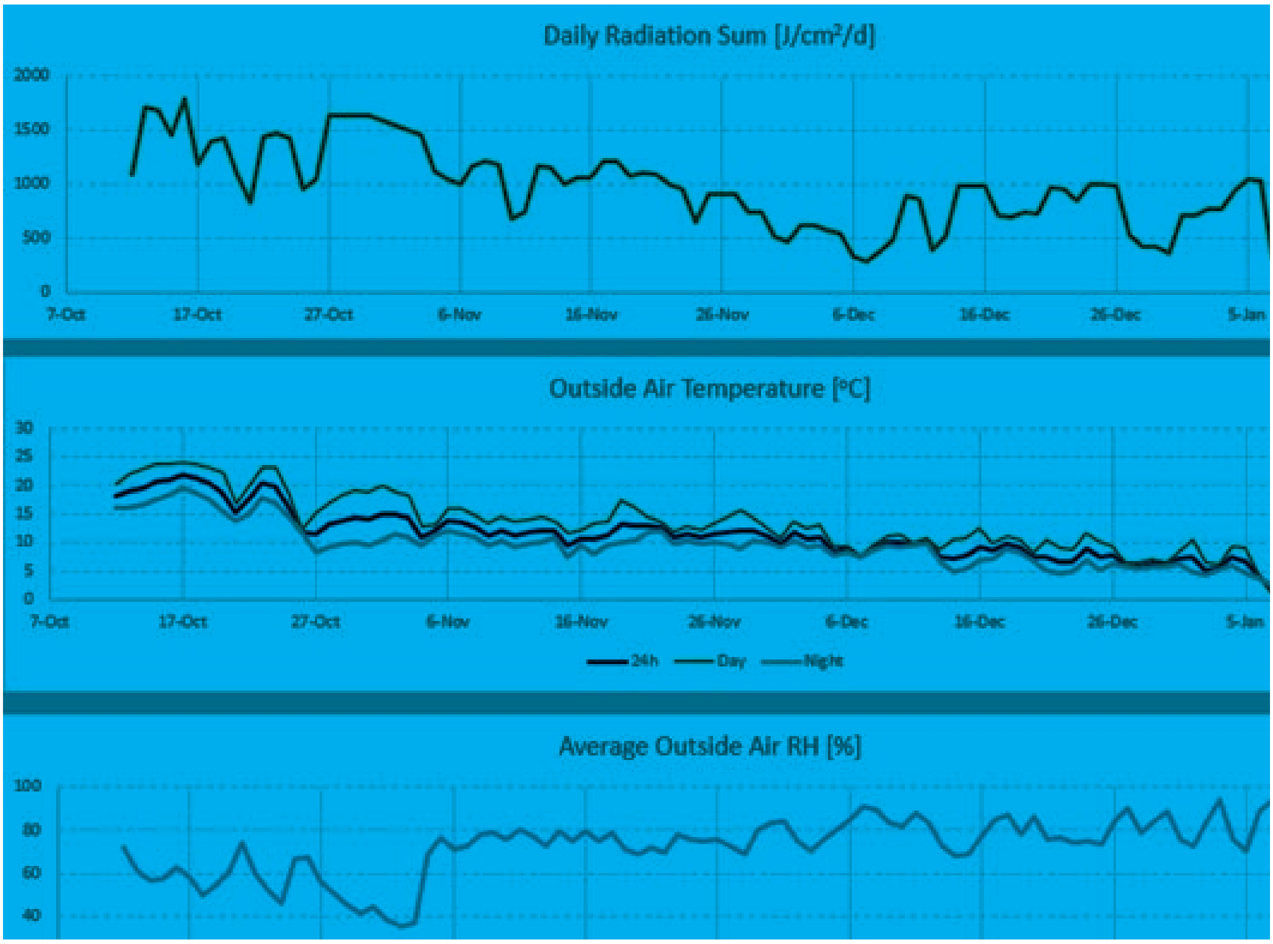


***Figure 24** Outside weather during the cucumber cultivation in autumn.*

The realized inside temperatures were better of course, mainly because the sun radiation increased average day temperatures to an acceptable level (Figure 25). Later it appeared (around November 26) that the improved tunnels had higher day temperatures as traditional tunnels. It appeared that the traditional tunnels were closed very late during the day (open front and rear doors from 8-17h). It appeared better to open the tunnels around 11h and close them already around 15h. In autumn it is much more important to keep the heat inside if no artificial heating is available than to lower the RH.

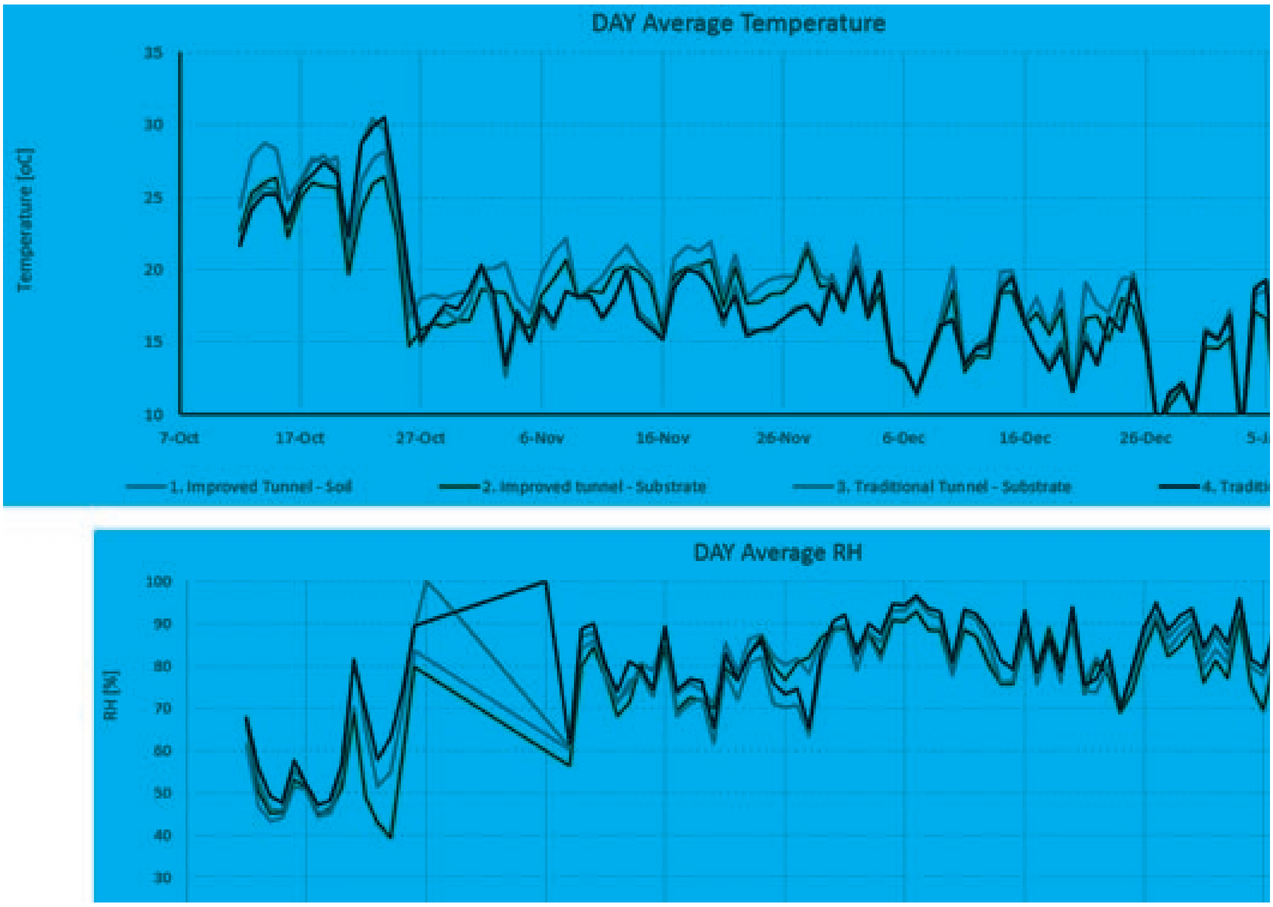


Figure 25 *Realized temperatures and RH inside the tunnels in cucumber crop (between 27 Oct and 7 Nov no RH data available).*

Passive heating
As it was already October and night temperatures dropped below 12°C it was decided to place the water filled sleeves again to see the effect in November and December (Figure 26).

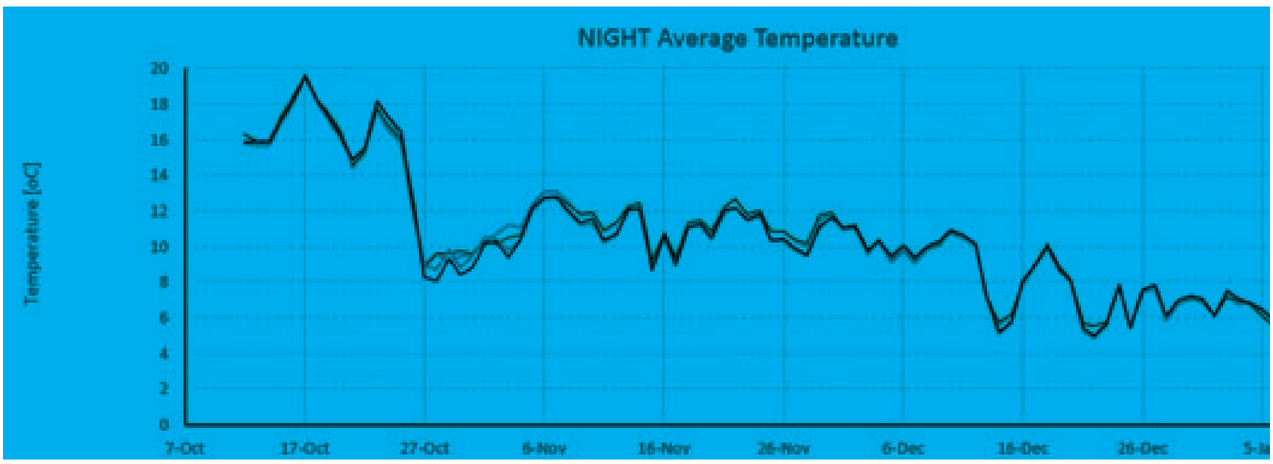


Figure 26 *Realized night temperatures in the 4 tunnels.*

Unexpectedly there is no difference in temperature between the tunnels. Only a few nights in December there is a minor difference (0.5°C). Further analysis also showed that the set-point of opening the improved tunnels for ventilation was from 11-12h. It was set to achieve a bit of ventilation at the warmest moment of the day.
In April, when the sleeves lead to a 3°C difference in temperature, there was a fixed liner to cover the crop. This liner could not be placed in autumn because of the high wire hooks.

4.2 Irrigation and water use

In Figure 27 an overview is given of the amount of water supplied to the plants. Even now the drainwater measurement was not functioning correct. Growth of plants in combination with an estimation of irrigation had to be made, the outcome is presented (Figure 27).

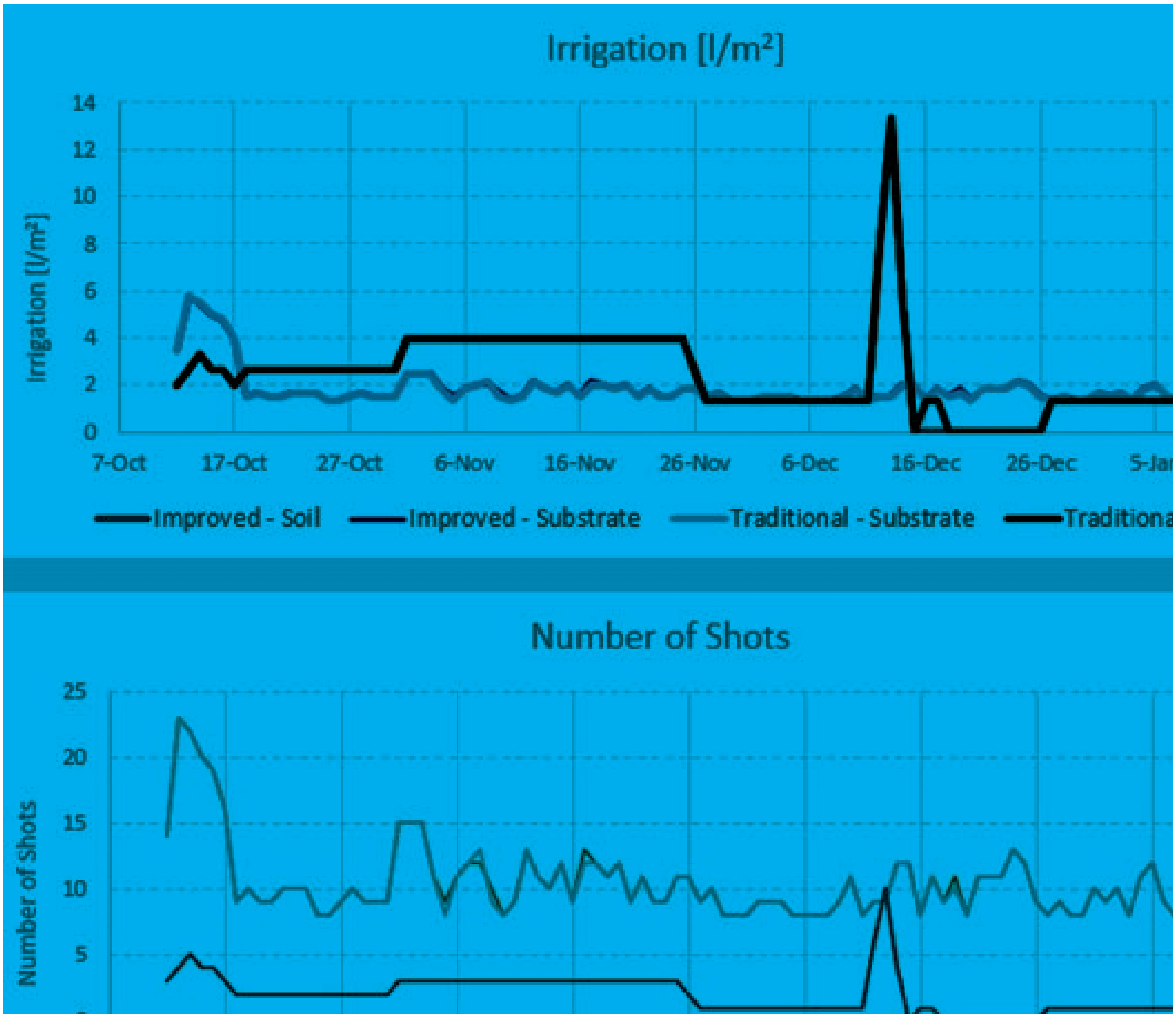


Figure 27 *Irrigation number of shots (lower graph) and calculated (upper graph) amount of water supplied to the plants.*

Irrigation started without adaptation of the tomato frequencies of irrigation. Initially this worked quite good. However early December it got too wet and set-points were changed, it resulted in a wrong strategy in soil (high peak), which was corrected, by stopping irrigation for a few days.

The total irrigation over the growing period was in soil about 156 - 184 L/m^2 and 118 - 150 L/m^2 in soilless cultivation. It resulted in a water use efficiency of respectively 135 – 170 L/kg for soil and 100 – 166 L/kg for soilless. The large variation in water use within soil (lower value for improved tunnel and higher value for traditional tunnel) was also seen at soilless. For this there is no explanation.

In October 2018, LARI has constructed a rainwater basin (6000 m^3) collecting rainwater from the surrounding buildings (1200m^2) and the 4 tunnels (Figure 28). The 2018-2019 winter season was wet, allowing to collect more than 5000 m^3 of rainwater, enough to change from well water to rainwater, but pumps and water meters had to be adapted.

Figure 28 *6000 m^3 rainwater collecting basin with entry pipe, rainbow and (right) dirty water from the roofs.*

4.3 Start of cucumber

The cultivation started in all tunnels at the same time: October 12, 2018 (Figure 29). Temperatures were favourable, so a good growth was expected. However 24h temperature started to decrease, especially after October 27. It resulted in a very slow growth of 10-20 cm in the first month (Figure 30) and after even much less. At December 31 the length of the plants was in the improved tunnels 134 cm and in the traditional tunnels 118 cm (Figure 33). Especially the plots close to the front door and in a lesser extend to the rear door were shortest, mainly because of a temperature effect.
Correction on all the data had taken place because a number of plants did not grow at all because of a blocked dripper. These plants were replanted, but results were off course different compared to the older plants.

Figure 29 *Just planted cucumber in 4 tunnels (Oct 12).*

Figure 30 *Early growth at Nov. 20. In Improved tunnels 6 water filled sleeves are placed.*

4.4 Yield of cucumber

First yield was on December 3, 2018 where it was expected by mid-November. From December onwards the pilot plots were harvested twice a week. Each plot consisted of 10 plants (4 m²) and there were 16 plots in total (4 per tunnel; Figure 31). Cultivation stopped when snow fell on the greenhouse at January 7, 2019. Temperatures decreased to 4°C outside and inside the tunnels.

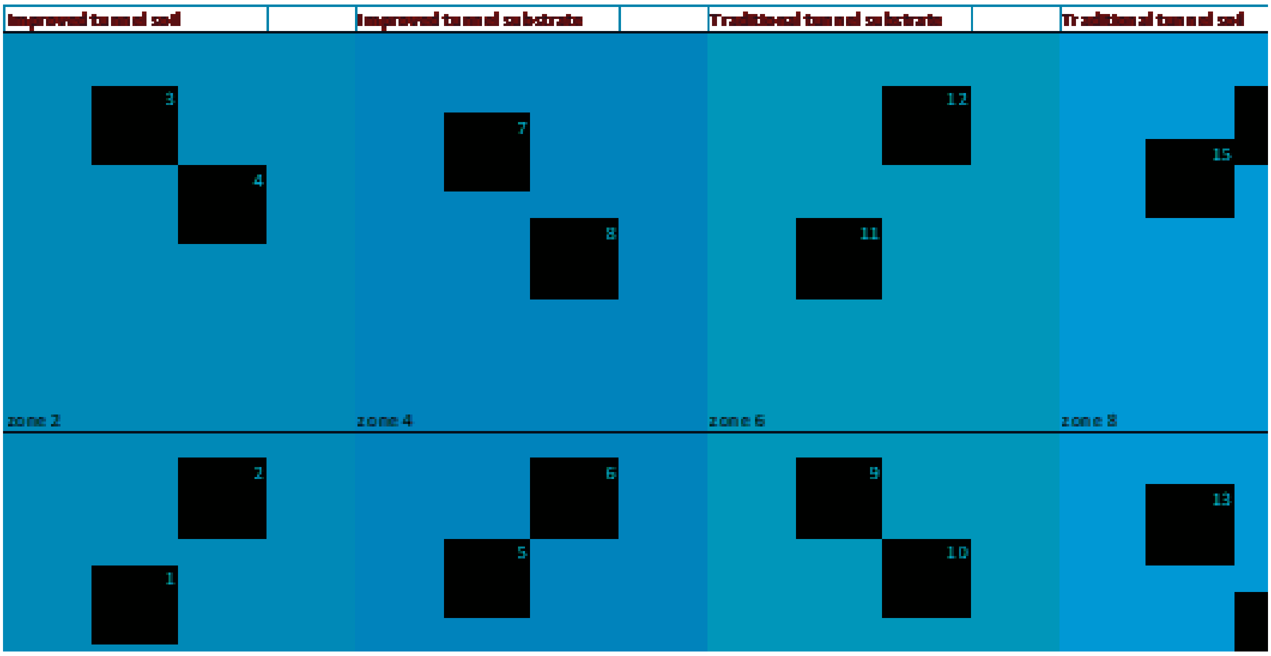


Figure 31 *Lay-out of pilot plots to be harvested, counted and graded.*

Table 3

Yield, quality and plant length per treatment from Dec. 3 2018 to Jan. 3 2019.

	Yield (kg/m²)	Number of fruits	Fruit weight (g)	Quality 1st (%)	Quality 2nd (%)	Plant length (cm)
Improved soil	1.22	18.4	66.5	50	40	134
Improved soilless	0.91	13.5	67.5	57	33	126
Traditional soilless	1.02	16.0	63.5	59	33	112
Traditional soil	0.89	14.8	60.2	52	39	115
Soil	1.06	16.6	63.7	51	39	125
Soilless	0.96	14.8	65.3	58	33	119
Improved grh	1.07	15.9	66.9	54	36	130
Traditional grh	0.95	15.4	61.9	56	36	114

The differences in yield between the treatments was small (table 3): yield from the improved tunnel in soil and from traditional tunnel with soilless cultivation were somewhat higher than the other treatments. Difference were not as pronounced as for tomatoes, probably due to the limiting climate conditions. Non marketable fruit was about 10%; 2nd quality was somewhat high, mainly caused by the non-favourable cucumber climate (Figure 33).

Figure 32 Plant status at Dec 31.

Figure 33 View on harvested cucumbers per zone at Dec 31 2018.

5 Discussion

The greenhouse demo centre built in the Bekaa valley was tested this year for the first time. Although it was a short time some remarkable topics appeared and will be discussed here.

Climate
Comparison between the simulated climate and the realized climate showed less differences as expected. In the traditional Lebanese tunnels the realized climate was mostly comparable with the improved ones. Passive heating showed a positive effect in temperature in April at the start of the cultivation, but not in the autumn having a short cucumber crop. Here the autumn absence of the fixed polyethylene liner at the top of the greenhouse might have given the difference. The same temperatures during day time in the summer might be caused by the orientation of the tunnels in relation with the wind direction. The wind direction was often parallel at the orientation of the tunnels which is in favour for the traditional tunnels while it was unfavourable for the improved tunnels. Differences in RH were mainly caused by the abundant irrigation of the soil compared to the dry climate and generative growth in soilless cultivation.

Cultivation
The cultivation in the improved tunnels showed for tomato big advantages, the introduction of the bumblebees was successful and created a better pollination resulting in a higher average fruit weight and a more constant fruit weight. The advantage of the possibility of having the head of the plant always in light conditions could not be tested because the growing season was too short, both for tomato and cucumber. The effect of less diseases in the insect netted improved greenhouse could also not be tested yet. In the first months it was a real challenge to close the doors after each visit to the improved tunnels. Differences in yield of tomato were caused by pollination in the improved tunnels and better generative growth in the soilless cultivation. Both were not yet optimised and can improve further. As cucumber pollination and vegetative/generative growth plays a minor role differences in yield were much less. Here the climatic data play a more important role: soil keeps much longer warm compared to the substrate, which was probably the main reason why cucumber growth in soilless cultivation was comparable or less than soil.

Irrigation
Irrigation in soilless cultivation is always a sum of plant uptake and amount of drain. As the latter could not be measured (yet), we could not determine the water use. Normally irrigation is adjusted based on the radiation. Now a more constant supply of water with nutrients was given. It resulted in a non-optimised water use. For both tomato and cucumber much less water can be supplied to optimise growth and to increase yield.

Economy
Growers were very much interested in using all the new technology, but their most important fear was the economic feasibility. A complete economic evaluation could not (yet) be made. However, the increased yield due to bumblebee pollination will pay itself back quickly. Certainly if combined with the high wire cultivation during the entire season.
A simple soilless system in combination with a cheap and reliable dosing installation should also be possible to steer the growth and immediately increase the yield and quality of fruits. The present dosing machine is too expensive but there are cheaper ones on the market.
The passive heating with sleeves and a plastic liner in top of the greenhouse are also cheap improvements which may extend the season with 2-4 weeks.

6 Conclusions and recommendations

Conclusions

The goal of the setup of a greenhouse demo centre in Lebanon was to save on water, to improve greenhouse cultivation and to disseminate the results to growers and technicians. The first year of the project was used for a market analysis, to determine the location(s) to design the demo centre, to negotiate with local parties about the terms of reference and finally to construct at LARI in Tal Amara in the Bekaa Valley the four chosen tunnels.
The second year, 2018, there were two cultivations (tomato and cucumber) in two improved and two traditional tunnels, either one with soil and one with soilless (coir) cultivation. Preliminary results are reported:

- The realized climate in the summer in the traditional and improved tunnels was similar. Ventilation in the traditional tunnels was sufficient due to the longitudinal wind direction. The extra ventilation capacity of the improved tunnels was not required this year.
- In the improved tunnels bumblebees could be introduced for pollination resulting in a more uniform and a higher average fruit weight.
- In soilless cultivation there was in tomato a much higher yield because of a strong generative steering of growth compared to soil.
- In cucumber the soil temperature increased yield in the soil tunnels compared to soilless.
- Passive heating with water filled sleeves on the ground and a plastic liner in the top of the tunnels showed increased night temperatures in April at the start of tomato. In autum with cucumber there was no plastic liner, temperatures were similar in improved and traditional tunnels.
- Irrigation was not optimal. In tomato there was an abundant start in soil which makes cultivation vegetative (many leaves, few kg), while in soilless cultivation it was too dry which gave a generative growth (many fruits on small plants). It showed the potential of soilless cultivation to steer the growth and to get the productivity as you like.
- Water saving could not yet achieved, technical failures were part of the process, but potentials have been shown.
- High wire cultivation was setup in the improved tunnels, but not fully exploited because of the short cultivation period of both tomato and cucumber.

Recommendations

Looking back to only one year of cultivation it is good to see what can be improved in a 2019 crop:

- Doing the same cultivation in the four tunnels but with less guidance from WUR;
- Creating a better long life tomato crop by hiring local help from experienced grower(s) but with applying the new technologies (soilless, high wire, vegetative/generative growth);
- Registration of water flows to steer the growth, but also to register yield as was done in last cucumber crop;
- Organising frequent visits of growers to show them how it is going, to convince them other methods are possible.

References

Baeza, E.J., Medrano, E., Sánchez-Guerrero, M.C., Sánchez-González, M.J., Porras, M.E., Giménez, M. and Lorenzo, P., 2017.
An alternative to conventional fossil fuel heating systems: water filled passive NIR absorbing polyethylene sleeves. Acta Hortic. 1170, p. 765-772.

Baeza, E., Van Os, E.A., Van der Salm, C., 2018.
Conceptual design of an optimum greenhouse for Lebanon, Bekaa Valley; presentation 39p.

El Halabi, D. 2018.
Application of Soilless Culture in Lari – Tal Amara, yield evaluation and water efficiency performance under traditional and improved greenhouses. Master Thesis faculty of Science at Lebanese University, 85p; 29 Sept. 2018.

El Rifai, L., 2018.
Evaluation of yield and water productivity of tomato crop in traditional tunnel and improved greenhouses. Master Thesis faculty of Science at Lebanese University, 89p; 29 Sept. 2018.

Ruijs, M., 2017.
Value chain analysis of (greenhouse) vegetables in Lebanon. Wageningen Economic Research, Memorandum 2017-102, 28p.

Van der Salm, C., Van Os, E.A., Baeza, E., Tsafaras, I., Jomaa, I., 2018.
Improving greenhouse production and water use efficiency in the Bekaa Valley, Lebanon; poster.

Van Kooten, O., Heuvelink, E., Stanghellini, C., 2008.
New developments in greenhouse technology can mitigate the water shortage problem of the 21st century. Acta Horticulturae 767, p. 45-53.

Van Os, E.A., Baeza, E., Jomaa, I., Zgheib, L., Van der Salm, C., El Halabi, D., El Rifai, L., Tsafaras, I., El Skaf, S., 2018.
A greenhouse with more ventilation to achieve a better production in Lebanon. Technical Information Sheet 1, 2p.

Van Os, E.A., Blok, C., Baeza, E., Jomaa, I., Zgheib, L., Van der Salm, C., 2018.
Soilless growing systems for higher production and to save water in Lebanon. Technical Information Sheet 2, 2p.

Van Os, E.A., Baeza Romero, Van der Salm, C. Tsafaras, I., Blok, C., Jomaa,I., 2019.
Application of the adaptive greenhouse concept in Lebanon. International symposium on mild winter climates and nettings, Tenerife, 25-29 January 2019.

Annex 1 Water supply and nutrient analysis

The way to calculate the amount of water supplied to the plants and what amounts (magnitude) should be seen on the water meters:

	substrate:	
capacity drippers:	2	l/h
time per irrigation	2	minutes
volume per irrigation per dripper	66.7	ml/turn
number of drippers per m2	2.5	dripper/m2
volume per m2 per irrigation	167	ml/m2
average number of shots	10	# of irrigations per day
irrigation in ml per day per m2	1667	ml/m2/day
in L/m2/day	1.7	l/m2/day
in L per zone (166m2)	277	liter per zone on flow meter p
	soil:	
capacity drippers:	4	l/h
time per irrigation	4	minutes
volume per irrigation per dripper	266.7	ml/turn
number of drippers per m2	5	dripper/m2
volume per m2 per irrigation	1333	ml/m2
average number of shots	3	# of irrigations per day
irrigation in ml per day per m2	4000	ml/m2/day

Estimated water use for cucumber, made before crop was planted:

	Water Use									water use (liters) per day					
			duration	evaporation		drain	water	in 1 zone	in 1 tunnel	used 2 tunnels	used 4 tunnels		fertilizer, 100x		
			weeks	estimation/day		%	use (l/m2)	166	520	640	1280	m2	have to be made	# Liters with one 1,000 tank	# Days with
1	young plant,	planting - 31 october	2	1-2	mm	15	1.7	276	552	1104	2208		300	10000	9.1
2	young crop,	31 October - end Mar	4	2-8	mm	50	3.9	644	1288	2496	4992		300	10000	4.0

Nutrient solutions for tomato and cucumber and analysis.
During visits water, coir and soil samples were taken and analysed by Groen Agro. Results are presented below.

	pH	EC	NH4	K	Na	Ca	Mg	Si	NO3	Cl	SO4	HCO3	H2PO4	Fe	Mn	Zn	B
		(mS/cm)	(mmol/l)	(mmol/l)	(mmol/l)	(mmol/l)	(mmol/l)	(mmol/l)	(mmol/l)	(mmol/l)	(mmol/l)	(mmol/l)	(mmol/l)	(µmol/l)	(µmol/l)	(µmol/l)	(µmol
Well Water Tal Amara	7.4	0.77	< 0.1	< 0.1	0.7	3.2	0.4	0.3	0.6	1.0	0.3	4.3	< 0.05	< 0.4	< 0.1	0.2	<
Rainwater Basin	7.1	0.11	< 0.1	0.2	< 0.1	0.3	< 0.1	< 0.1	< 0.1	0.1	0.1	0.5	< 0.05	1.7	< 0.1	1.7	<
nutrient solution, open system, coir																	
tomato	5.3	2.6	1	9.3		5.5	2.4		14.0		4.4		1.5	30	10	5	3
cucumber	5.3	2.2	1	8		4.5	1.5		16.75		1.5		1.25	30	10	5	2
target values around the roots (coir)																	
tomato	5.5-6.0	1.5	<0.05	2.0	<2	3.0	1.0		8.25	<2	2.5	<0.05	0.5	15	2	5	2
cucumber	5.2-6.0	1.4	<0.05	3	<2	3	1.5		8	<2	1.5	<0.05	0.7	10	3	4	2
Analysis done at Groen Agro																	
Mixing Tank (values comparable with nutrient solution)																	
tomato 7-6-2018	6.5	1.9	0.58	5.3	0.7	4.6	1.5	0.2	8.0	1.5	2.2	2.5	0.85	4.3	54.0	24.0	17
20-07-2018	6.6	2.2	0.6	7.2	0.9	5	1.6	0.3	8.5	2.1	2.4	3.5	1.2	11.1	11.0	3.7	4
Drainwater (values comparable with target values																	
Zone 3 20-7-2018	7.9	4.0	< 0.1	19.5	5	8.3	4.1	1.6	16	9	9.1	3.7	0.1	16.7	1.1	1.1	16
Zone 4 20-7-2018	7.5	3.0	< 0.1	14.6	3.9	6.3	3.5	0.9	13.1	7.4	6.2	2.9	0.3	11.3	2.7	1	9
Zone 5 20-7-2018	7.5	2.7	< 0.1	9.9	2.4	4.0	2.4	0.7	10.1	4.5	3.9	2.2	0.3	7.4	2.1	0.6	8
Zone 6 20-7-2018	7.3	3.2	< 0.1	11.6	2.2	5.9	2.9	0.8	12.7	4.9	5	1.9	0.2	8.3	3.1	1.2	5
Coir slab water 20-07-2018	7.3	6.1	< 0.1	23.2	5.9	12.6	7.1	2.2	16.3	12.0	13.7	9.5	< 0.05	23.3	1.5	1.6	5
cucumber																	
mixing tank 31-10-2018	6.6	2.6	0.2	11.2	0.7	5.3	0.6	0.2	16.5	1.3	0.6	2.3	0.5	4.7	4	2.4	8
05-12-2018	3.5	2.2	0.8	6	0.7	4.6	1.7	0.2	8.9	2.1	4.1	< 0.1	1.1	5.9	15.5	13.7	3
Draintank, zone 6 31-10-2018	7.1	3.1	1.3	14	2.9	3.5	2.0	0.9	8.6	5.3	4.9	4	1.1	2.6	0.9	0.1	12
Draintank, zone 5 5-12-2018	7.8	1.6	< 0.1	5.1	1.5	3.2	1.3	0.4	3.7	3.3	1.9	3.5	0.15	1.3	< 0.1	0.1	2
Draintank, zone 6 5-12-2018	7.8	2.6	< 0.1	10.7	2.3	3.9	2.5	0.7	7.2	4.6	4.3	3.7	0.25	2.9	< 0.1	0.3	5
Coir, tunnel 3 5-12-2018	7.1	1.1	< 0.1	4.1	1.2	1.4	0.8	0.2	2	2.1	2	0.7	0.05	7.7	0.7	0.2	3
Coir, tunnel 2 5-12-2018	6.9	1.1	< 0.1	4.3	1.6	1.4	0.9	0.3	1.7	2.1	2.6	0.5	0.1	5.7	0.2	0.3	2

Annex 2 Construction of the tunnels

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

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The mission of Wageningen University and Research is “To explore the potential of nature to improve the quality of life”. Under the banner Wageningen University & Research, Wageningen University and the specialised research institutes of the Wageningen Research Foundation have joined forces in contributing to finding solutions to important questions in the domain of healthy food and living environment. With its roughly 30 branches, 5,000 employees and 10,000 students, Wageningen University & Research is one of the leading organisations in its domain. The unique Wageningen approach lies in its integrated approach to issues and the collaboration between different disciplines.