Design of a greenhouse for peri-urban horticulture in Algeria

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Referaat
In deze studie is een optimale kas ontworpen voor gebruik in de kustvlakte rond Algiers. De resultaten gaven aan dat er twee opties zijn voor een optimale productie van een voorbeeld gewas als tomaat. Er is een mogelijkheid om in de winter te telen in een verwarmde kas of in de zomer met behulp van air conditioning in combinatie met CO_2 toediening. De opbrengsten van beide systemen zijn vergelijkbaar maar de kosten voor de winterteelt zijn ruim 30% lager. De investeringskosten voor het zomersysteem zijn hoger maar het zomersysteem leidt wel tot een lager (aanvullend) watergebruik en lagere energiekosten. Om water en kosten te besparen wordt geadviseerd om gebruik te maken van substraat, recirculatie van water en de opvang van regenwater in een water bassin. Alternatieve gewassen als sla en aardbei kunnen een optie zijn voor de vroege winter en vroeg voorjaar indien gekozen wordt voor een teelt zonder verwarming

Abstract
In this study a greenhouse has been designed for optimal production in the coastal area close to Algiers. Data showed that there are two main options for optimal production of tomatoes and similar products like cucumber. A choice can be made for winter production in a heated greenhouse or summer production with air-conditioning and CO_2 injection. The estimated production is fairly similar for both seasons but the costs for summer production are 30% higher. The investment costs for the summer production scenario are higher but running costs are lower, since in summer less additional water and energy are needed for the production. To reduce the use of water and related costs we recommend to grow on substrate, re-circulate the water and collect the rainwater in a water basin. The growth of salad or strawberries might be an alternative for cultivation in early winter or early spring in greenhouses without heating.

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Summary

Algeria is a large country with a large internal market to feed its own population. At the moment Algeria is partly dependent on production in the southern part of the country (6000 ha greenhouses out of 16000 ha, 50% annual production). However, production in this area is not sustainable due to the increasing scarcity of water and the long-distance transport, with a high CO_2 food print and a negative effect on product quality. Conditions in the north coastal area are more favourable with respect to climate and distance to consumers but nearly each square meter in this area is already in use. Therefore, horticulture production should become more water and energy efficient, more sustainable, to create a higher production and quality close to the economic markets of Algiers and other cities. The climate in the northern region is ideal for greenhouse production. Optimization of the greenhouse design and renewal of greenhouses in combination with more modern cultivation techniques could help to overcome this issue and come up to an improved agricultural system for Algeria.

The Dutch embassy, in close cooperation with the Ecole Nationale Superieure Agronomic (ENSA), wants to develop a better peri-urban agricultural system for the northern part of Algeria. Single plastic tunnels are widely used in Algeria, both in the North in the coastal area as in the South around Biskra. In 2012 Van Os *et al.* showed some improvements to be made (single tunnels with more ventilation, optimized multispan greenhouses.

The design of a suitable peri-urban horticultural system, in this study, was based on the adaptive greenhouse design. An adapted greenhouse is a greenhouse with a number of innovation compared to the present tunnels but also achievable for existing growers. In such a greenhouse growers can earn more money and with the profits they can further invest in the greenhouse. Present tunnels in the Mediterranean often have too little ventilation (resulting in too high temperatures and a shorter growing season).

This study is based on simulations with the greenhouse model KASPRO-INTKAM (De Zwart, 1996; Gijzen, 1994, Vanthoor *et al.,* 2011) using tomato as a reference crop for Algiers. Data showed that there are two main options for increased production of tomatoes and similar products like cucumber. A choice can be made for winter production (September-July) in a heated greenhouse or summer production (April- December) with cooling. The estimated production is fairly similar for both seasons at approximately 40 kg/m^2 for a heated or an air conditioned greenhouse with CO_2 application. The costs are approximately 30% higher for the summer production due to higher investment costs. At the same time market prices of tomatoes will be higher in winter compared to summer. All figures are based on an optimal management and no loss of production due to pests or diseases.

An alternative to a high tech greenhouse with air-conditioning is the use of a pad&fan system for cooling. The investment is considerably lower (approximately 80 €/m^2 compared to 280 €/m^2) leading to an even lower cost price per kg tomatoes compared to winter cultivation. However, the climate in the pad&fan system is less favorable. Simulated humidity was quite high, leading to higher risks for fungal diseases. Another option for cooling which was considered was the use of shading screens. The simulation shows that with shading screens there are less hours that are too hot, which potentially could lead to higher yields. Nevertheless, it is expected that shading will cause issues with the vegetative to generative crop balance. Therefore, it is unclear whether shading will actually bring the predicted benefits.

All systems without heating or cooling have much lower production rates (less than 10 kg/m^2) due to the limited length of the growing season (no production from December to April and in July and August) and less favorable temperature conditions during the cultivation periods.

The use of substrate, the recirculation of water and the use of basin for rainwater collection reduces the use of water for cultivation. The greenhouse with air-conditioning leads to the lowest water use as the evaporated water can be recaptured by the air-conditioning. In winter cultivation the water use is higher but still low compared to summer cultivation with a pad&fan system.

Strawberry and lettuce can grow at lower temperatures and may be more suitable for cultivation without heating in winter. These crops might also be interesting for smaller growers, who cannot invest in heating or cooling and like to combine an autumn/spring growth of tomato/cucumber with an early winter/early spring cultivation of salad or strawberry.

1 Introduction

Algeria is a large country with a large internal market to feed its own population. At the moment Algeria is partly dependent on production in the southern part of the country (6000 ha greenhouses out of 16000 ha, 50% annual production). However, production in this area is not sustainable due to the increasing scarcity of water and the long-distance transport, with a high CO_2 foot print and a negative effect on product quality. Conditions in the north coastal area are more favourable with respect to climate and distance to consumers but nearly each square meter in this area is already in use (Figure 1.1). Therefore, horticulture production should become more water and energy efficient, more sustainable, to create a higher production and quality close to the economic markets of Algiers and other cities. The climate in the northern region is ideal for greenhouse production. Optimization of the greenhouse design and renewal of greenhouses in combination with more modern cultivation techniques could help to overcome this issue and come up to an improved agricultural system for Algeria.

The Dutch embassy, in close cooperation with the Ecole Nationale Superieure Agronomic (ENSA), wants to develop a better peri-urban agricultural system for the northern part of Algeria. Single plastic tunnels are widely used in Algeria, both in the North in the coastal area as in the South around Biskra. In 2012 Van Os *et al.* showed some improvements to be made (single tunnels with more ventilation, optimized multispan greenhouses). Since that time new construction types and heating alternatives were developed for the Mediterranean area (Baeza et al. 2017; Baeza *et al.,* 2019) which might be a good option for the coastal area of Algeria. The principle of the adaptive greenhouses has been applied here: make a greenhouse affordable for the local grower (technology and knowledge level; economic investments; market prices) which functions well in the local climate. Besides it was investigated if soilless cultivation can help to improve production and quality of produce compared to the traditional soil growing methods. Methods of cultivation were evaluated and improved if possible. Soilless cultivation opens possibilities to be 50% more water and fertilizer efficient (Blok *et al.,* 2020). However a good water quality is demanded but can partly be achieved with the regaining of the precipitation which is traditional in the Netherlands but not common in Algeria. The latter has to be incorporated in the greenhouse design.

The aim of this study is to come to a design of a sustainable greenhouse for vegetable production which fits the local climate and makes efficient use of space, water, energy and which is affordable for the local growers.

Figure 1.1 *Google air picture of Algerian single tunnel greenhouses (close to Boudouaou), as an example.*

1.1 Climatic constraints for greenhouse horticulture in Algiers

Looking to the climate the yearly solar radiation sum is around 6.5 GJ/m²/year in Algiers (compare The Netherlands, 3.8 GJ/m²/year). The minimum temperatures are below 5°C in winter whereas summer temperatures are above 30°C (Figure 1.2). This indicates that both ventilation, heating, and cooling should be considered if year-round production is desired (Figure 1.2). Summer temperatures are high but not extreme because of the sea. The wind speed during the day is normally over 2 m/s. With an average precipitation of 550 mm/year in Algiers, it is possible to collect and store rainwater for irrigation and hydroponics (Van Os *et al.,* 2012, 2017). In summary, there is a good climate for greenhouse cultivation. However, greenhouse design could be optimized compared to present single tunnels (Van Os *et al.,* 2017). Optimization could lead to higher productivity. Limited data on present productivity leads to the conclusion that average yearly tomato yields are 5-10 kg/m², while in some cases up to 20-30 kg/m² are produced. In 2012 there was 8000 ha of tunnels in this area, which shows the enormous potential if optimization of design in greenhouses and growing methods could be realized to increase production in the peri-urban environment.

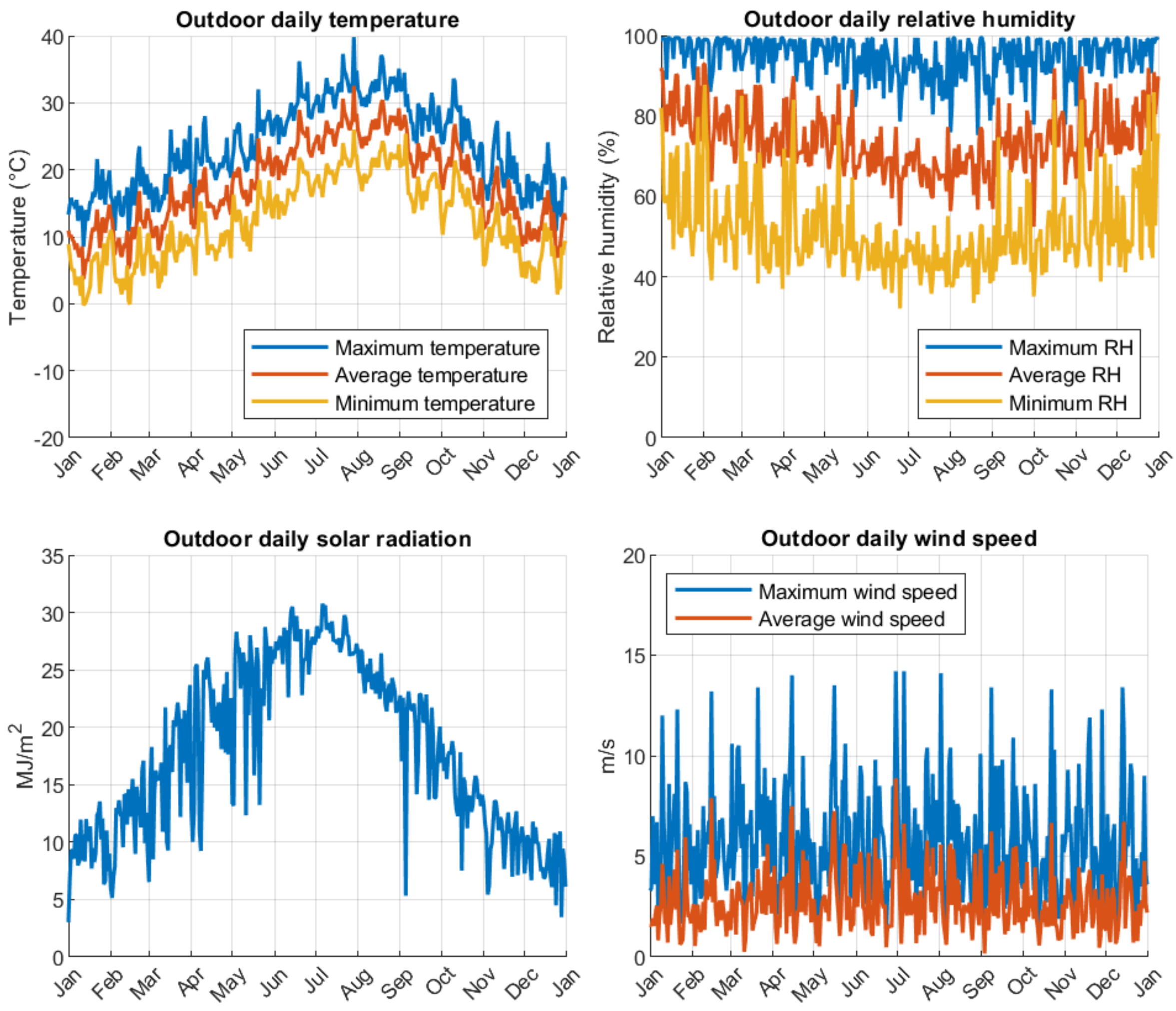


Figure 1.2 *Weather conditions in Algiers during a typical meteorological year.*

1.2 Approach

The design of a suitable peri-urban horticultural system was based on the adaptive greenhouse design. An adapted greenhouse is a greenhouse with a number of innovations compared to the present tunnels but also achievable for existing growers. In such a greenhouse growers can earn more money and with the profits they can further invest in the greenhouse. Present tunnels in the Mediterranean often have too little ventilation (resulting in too high temperatures and a shorter growing season). Improved tunnels have more ventilation, or are shorter in length. A multispan is more expensive but for modern growers they provide better options for a optimal production with increased quality a market with higher prices per kg produce. The basis of the design is a simulation of the interior climate of the greenhouse (Chapter 2). Based on this, options for the greenhouse construction (Chapter 3) and the interior design (Chapter 4) are presented. Finally an economic analysis is made for the different options (Chapter 5) and conclusions and recommendations are presented (Chapter 6).

2 Simulation of the greenhouse climate

2.1 Methods

The greenhouse simulation model KASPRO-INTKAM (De Zwart, 1996; Gijzen, 1994) was used to simulate a tomato greenhouse in Algiers. Weather data was based on a standard meteorological year in Algiers, Algeria, generated by Meteonorm (Remund *et al.,* 2020). As the goal of the simulation was to test feasibility and capacities, the initial greenhouse construction settings were set according to standard practice in the Netherlands. The window ventilation area was set to 5% of the greenhouse floor area, based on the common situation in Algeria (Van Os *et al.,* 2012).

Simulations were performed with a tomato as a reference crop. The baseline air temperature setpoints for this crop (which were relevant to scenarios with active greenhouse control like heating or cooling) were 17°C at night, 19°C at day, with a "dip" to 15°C in the first two hours after sunset. On top of this baseline, a "radiation temperature ratio" was maintained: the setpoints were continuously adjusted so that the average 24-hour indoor temperature depended on the amount of available sunlight per day: the base target average 24-hour indoor temperature was 16°C. This target average 24-hour indoor temperature was increased by 0.2°C for every mol/m^2/day of PAR light. The setpoints calculated according to this "radiation temperature ratio" were considered the optimal temperatures for tomato growth.

2.1.1 Simulated scenarios

As an initial simulation, a greenhouse scenario with a static, small crop (leaf area index constant at 0.5) was simulated over a full year. This greenhouse had only manual control of ventilation (see below), ventilation area of 5%, no heating, screens, or cooling. This simulation was used to determine the growing periods for the winter and summer cultivation simulations. The winter cultivation season was chosen such that a favorable temperature and humidity range for tomato can be achieved without cooling. The summer cultivation season was chosen such that a favorable range can be achieved without heating. A favorable temperature range for tomato was set as an average daily air temperature of 18-22°C, and a favorable air humidity range was set at 67-92% relative humidity.

After the initial simulation, winter simulations were performed. Four scenarios were tested:

1. **Manual ventilation.** In this scenario, the greenhouse had no heating or screens. Ventilation was assumed to be done by hand. The windows were fully open from sunrise to sunset, and fully closed during the night. The ventilation area (window area divided by total floor area) was 5%. In the months July and August, the windows were always fully open. Practically it means that the front and rear end doors are open and sometimes a slit is made between plastic strips covering the tunnels (Figuur 3.1).
2. **Automatic ventilation.** In this scenario, the greenhouse had no heating or screens, but ventilation was assumed to be controlled by a climate computer according to common standards in the Netherlands. The ventilation area (window area divided by total floor area) was 15%. Ventilation windows were opened if the indoor temperature was 2 °C above the temperature setpoint, or if the indoor relative humidity was above 85%. Practically it means a multispan greenhouse with window which can be opened and closed based on the mentioned setpoints.
3. **Automatic ventilation + energy screen.** Same as "automatic ventilation", but with an energy screen, which was closed whenever the outdoor temperature was below 5°C.
4. **Automatic ventilation + energy screen + heating.** Same as the previous scenario, but with a heating system, which could supply up to 175 W/m^2 of heating to the greenhouse.

Next, summer simulations were performed. Six scenarios were initially tested:

1. **Manual ventilation.** Same as the "manual ventilation" scenario above.
2. **Automatic ventilation.** Same as the "automatic ventilation" scenario above.
3. **Automatic ventilation + fogging.** Same as "automatic ventilation", but with fogging used for cooling and humidification. The fogging capacity was set at 400 g/m^2/hour.
4. **Pad and fan.** Climate was controlled with a pad and fan cooling system. In this case, a wet pad and fan were installed instead of window ventilation. The capacity of the pad and fan system to pull air into the greenhouse was 100 m^3/m^2/h. When the system functioned for dehumidification (with dry pads), the maximum capacity was 10 m^3/m^2/h.
5. **Air conditioning no dehumidification.** Climate was controlled with an air conditioner with a cooling power of 700 W/m^2. which simultaneously cools and dehumidifies the greenhouse. There was no window ventilation. The air conditioner operated only when the greenhouse was too warm.
6. **Air conditioning with dehumidification.** Same as the previous scenario, but the air conditioner also operated if the greenhouse was too humid, even if temperatures were not too high.

In addition to the above 6 summer scenarios, another 6 summer scenarios were examined: the first 5 were identical to the above scenarios 2-6, but a shading screen was employed in order to cool the greenhouse. The screen was closed by 80% if the outdoor temperature was above 25^{o}C and the sunlight intensity was above 500 W/m^2. The screen was closed by 100% if the outdoor temperature was above 25^{o}C and the sunlight intensity was above 700 W/m^2. The last scenario considered the case of air conditioning with dehumidification, and with the injection of CO_2. In this case, the maximum CO_2 injection rate was 100 kg/ha/hour.

2.1.2 Yield, water, and energy use estimates

In order to estimate yield, including the influence of too high or too low temperatures, a model for the influence of temperature on tomato growth (Vanthoor *et al.,* 2011) was included to modify the yield prediction of the original INTKAM model. The Vanthoor model was used to calculate a "reduction factor" in yield, which had two factors:

Yield reduction based on momentary temperature: yield was 0 if the momentary crop temperature was below 6^{o}C or above 40^{o}C. Yield was not reduced if momentary crop temperature was between 14-28^{o}C. Between 6-14^{o}C and 28-40^{o}C yield was reduced by linear interpolation.
Yield reduction based on 24-hour average temperature: yield was 0 if the average crop temperature in the previous 24 hours was below 12^{o}C or above 27^{o}C. Yield was not reduced if the average crop temperature in the previous 24 hours was between 18-22^{o}C. Between 12-18^{o}C and 22-27^{o}C yield was reduced by linear interpolation.
Crop death: the crop was assumed to be dead if the yield reduction factor was 0 for 48 consecutive hours.

Note that this yield model ignores the issue of "radiation temperature ratio" explained above. This should be understood as follows: the "radiation temperature ratio" helps to estimate the vegetative-generative balance of the crop. A crop that is far from the optimum according to this ratio will likely be out of balance and will be very difficult to manage. The yield model, however, ignores this issue and just gives information about the potential yield, including the influence of adverse temperature.

It should be noted that the yield estimates assume optimal crop handling (besides the influence of temperature). Therefore, these estimates represent potential yield, where crop management - irrigation, fertilization, disease and pest control, handling - is all done in an optimal manner. Furthermore, the assumption is that plant starting material is big, with first flowers already appearing on the plant (similar to common practice in the Netherlands). With this management and handling, the first harvest can be done approximately 8 weeks after planting.

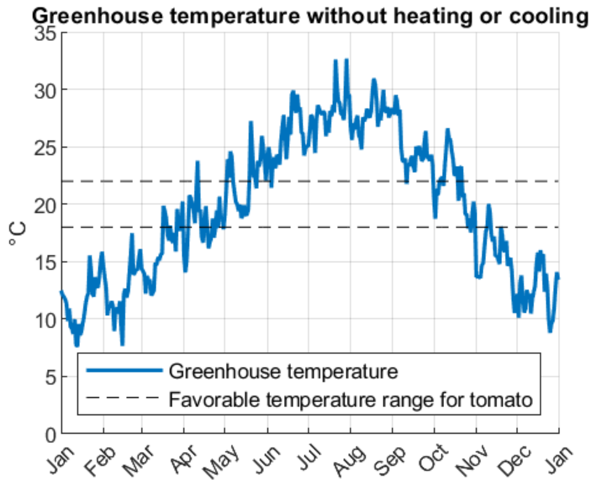
Water use was estimated by multiplying the simulated crop transpiration by 1.1. This estimated water use represents an optimal irrigation control, on substrate, with minimal drainage. Therefore, as in the case of yield, this should be seen as a potential or an optimum.

Water, electricity, and gas use calculations were based on the assumption that cultivation stops if the crop dies.

2.2 Results

2.2.1 Year round simulation

The initial year round simulation shows some of the main challenges in growing a greenhouse tomato crop in Algiers (Figure 2.1). Without climate control equipment, the greenhouse is too cold between November and March, and too hot between June and August. Throughout the year, there are moments with too high humidity in the greenhouse. In July and August, the greenhouse air is often too dry.



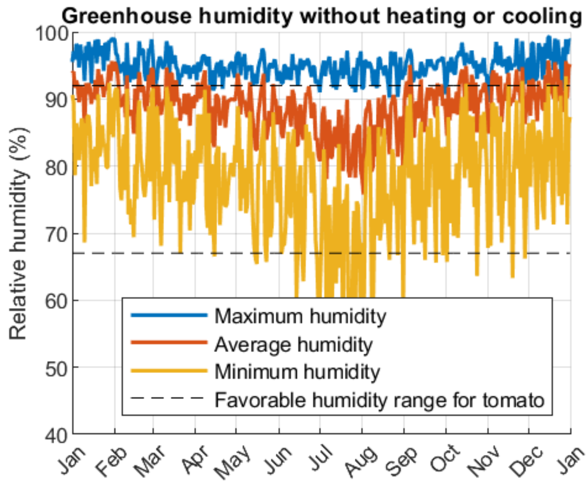


Figure 2.1 *Indoor temperature and humidity for a manually controlled greenhouse throughout the year.*

Based on these results, the simulated winter and summer growing cycles were determined. For the winter cycle, the simulated season was from September to June. This is a potential growing season if the cold moments in winter can be overcome. For the summer cycle, the simulated season was from April to November. This is a potential growing season if the hot moments in summer could be overcome.

2.2.2 Winter cultivation

All the winter scenarios, except for the scenario with heating, were not able to maintain favorable temperatures for tomato growing between November and April (Figure 2.2). With heating, temperatures were maintained very well, and were equivalent to the optimal temperature according to the "radiation temperature ratio".

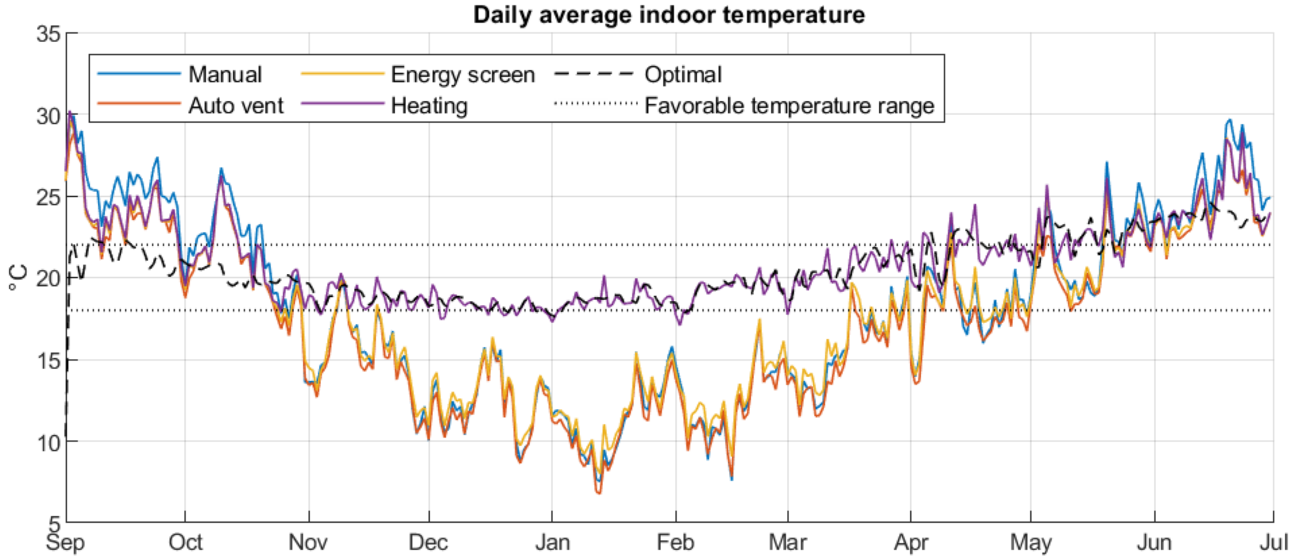


Figure 2.2 *Indoor temperature for the winter cultivation simulations.*

Without heating, there were also many days with high relative humidity (Figure 2.3). With heating, also relative humidity was controlled very well.

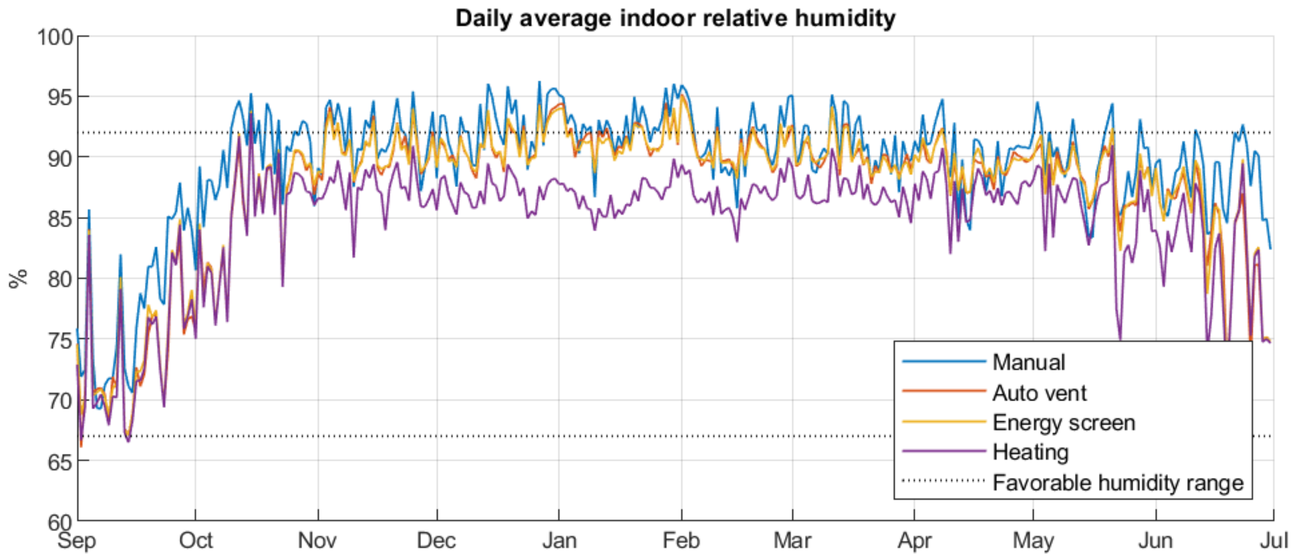


Figure 2.3 *Indoor relative humidity for the winter cultivation simulations.*

The potential tomato yield for the greenhouse with heating is predicted to be close to 40 kg/m^2 (Figure 2.4). Without heating and no screens, the crop is predicted to die about 3 months after planting, and about 1 month after first harvest. With screens, the crop can survive one more month. In this way, yield is predicted to be around 3-4 kg/m^2. Naturally, in these conditions a new crop (possibly a more cold-tolerant crop) can be planted after the tomato crop death.

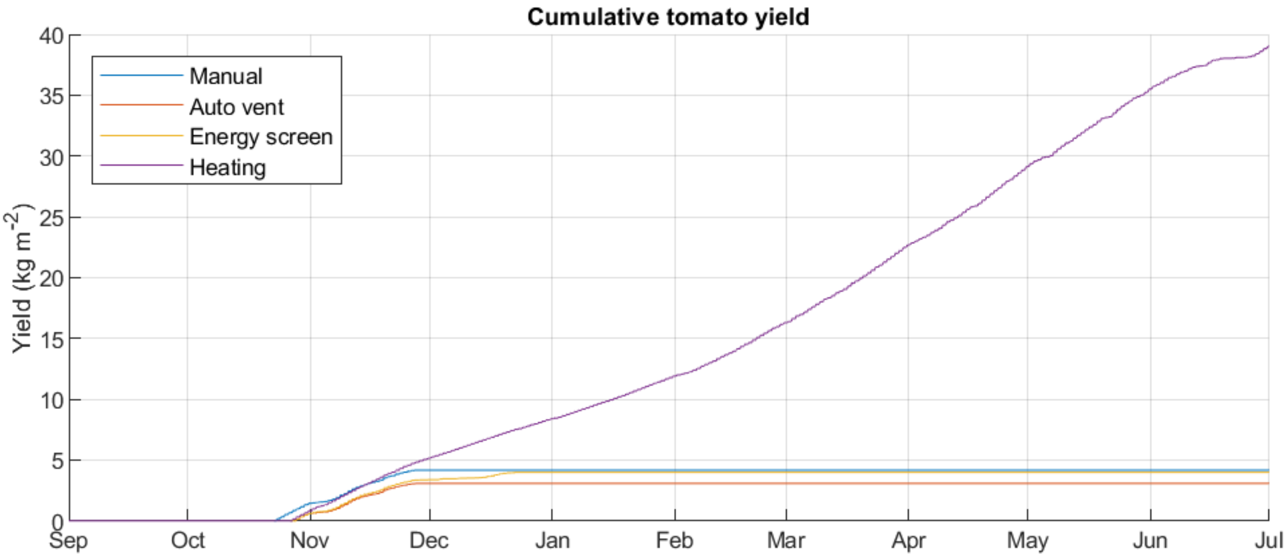


Figure 2.4 *Potential crop yield for tomato cultivation in winter.*

In summary, the technical details of the simulated winter cultivation scenarios are given in Table 2.1.

Table 2.1
Technical details of simulations for winter cultivation of tomato.

	Variant 1 Manual ventilation	Variant 2 Automatic ventilation	Variant 3 Automatic ventilation + screen	Variant 5 Automatic ventilation + screen + heating
Planting date	September 1	September 1	September 1	September 1
First harvest	October 23	October 28	October 28	October 27
Last harvest	November 27	November 27	December 22	July 1
Ventilation and ventilation area	Manual, 5%	Automatic, 15%	Automatic, 15%	Automatic, 15%
Boiler type and heating capacity	-	-	-	Natural gas, 175 W/m^2
Screens	-	-	Energy screen	Energy screen
Potential water use (litres/m^2)	206	219	254	1000
Gas use (m^3/m^2)	-	-	-	18
Potential yield (kg/m^2)	4	3	4	39
Comments	- High risk of disease due to high humidity	- High risk of disease due to high humidity	- High risk of disease due to high humidity	

2.2.3 Summer cultivation

All the summer scenarios without the shading screen, except for the scenario with an air conditioner, were not able to maintain favorable temperatures for tomato growing in July and August (Figure 2.5). With air conditioning, temperatures were maintained very well, and were equivalent to the optimal temperature according to the "radiation temperature ratio". If air conditioning was also used to control for dehumidification, the temperature in the greenhouse were typically colder than the optimum, and in September-December also lower than the range for good tomato growth.
Note that for the case of air conditioner with no dehumidification, the temperatures follow the optimal temperature according to the "radiation temperature ratio", but are still outside the favorable temperature range. This would indicate that the crop will likely maintain a good vegetative to generative balance, but may also have a lower yield due to too high temperature in the current model.

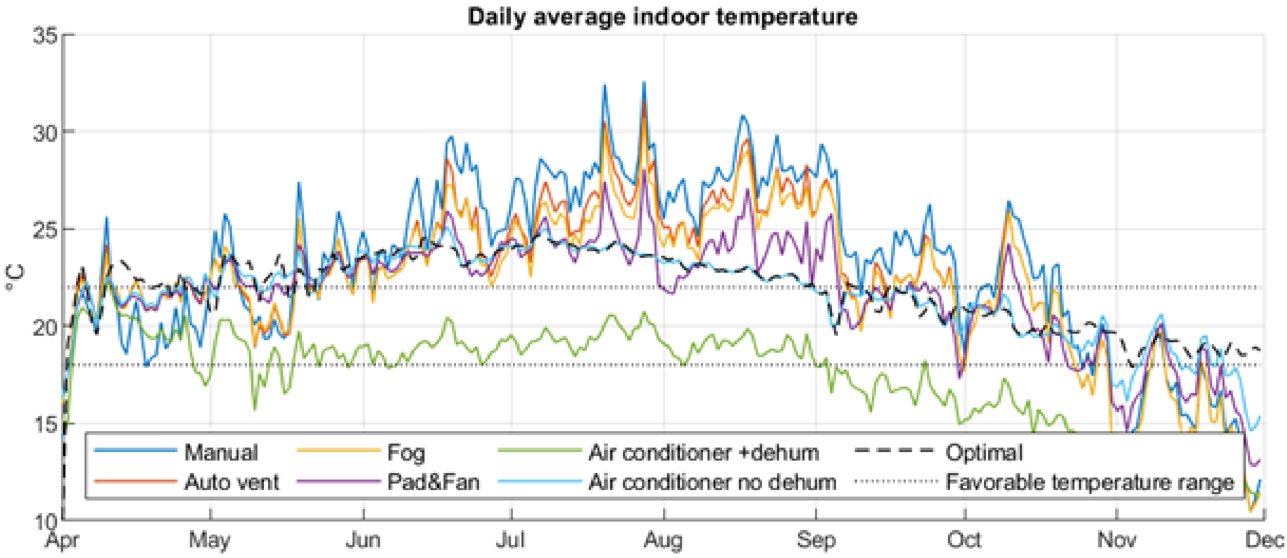


Figure 2.5 *Indoor temperature for the summer cultivation simulations without shading screens.*

Humidity was maintained quite well in the manual, automatic ventilation, and fogging scenarios. When air conditioning is used for dehumidification, humidity is maintained well, except at the end of the season (October-December) (Figure 2.6). This indicates that if an air conditioning system is present, its control should be done in a smart way, in order to find a balance between maintaining humidity within the safe range without cooling the greenhouse too much.

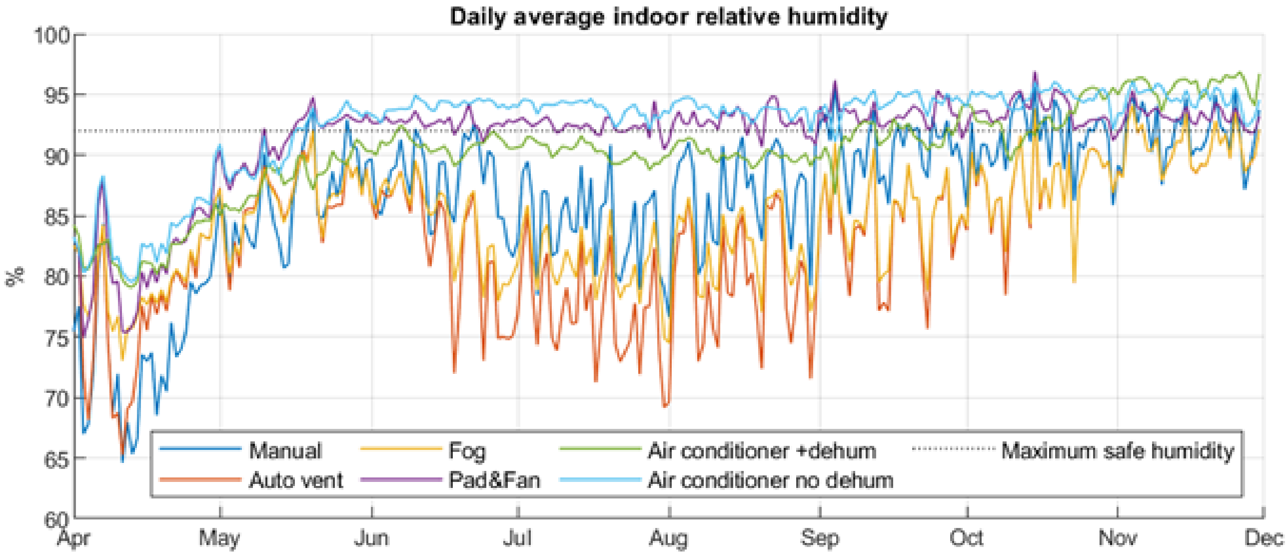


Figure 2.6 *Indoor relative humidity for the summer cultivation simulations without shading screens.*

The influence of shading can be seen in Figure 2.7. It can be seen that shading has a small influence in cooling the greenhouse, and does very little to help cool the greenhouse in the hottest months of July and August. The main problem with shading is that by reducing the radiation in the greenhouse, also the optimal temperature is reduced, due to the "radiation temperature ratio" principle. Therefore, with shading the temperatures are even farther from the optimum than they are without shading. This indicates that with shading, there is a risk that the crop will become "out of balance": with temperatures high above the optimum the plant will become weak, will stretch and have thin stems. At that moment the crop will also be more vulnerable for pests and diseases. A similar effect is seen for pad and fan cooling in Figure 2.8.

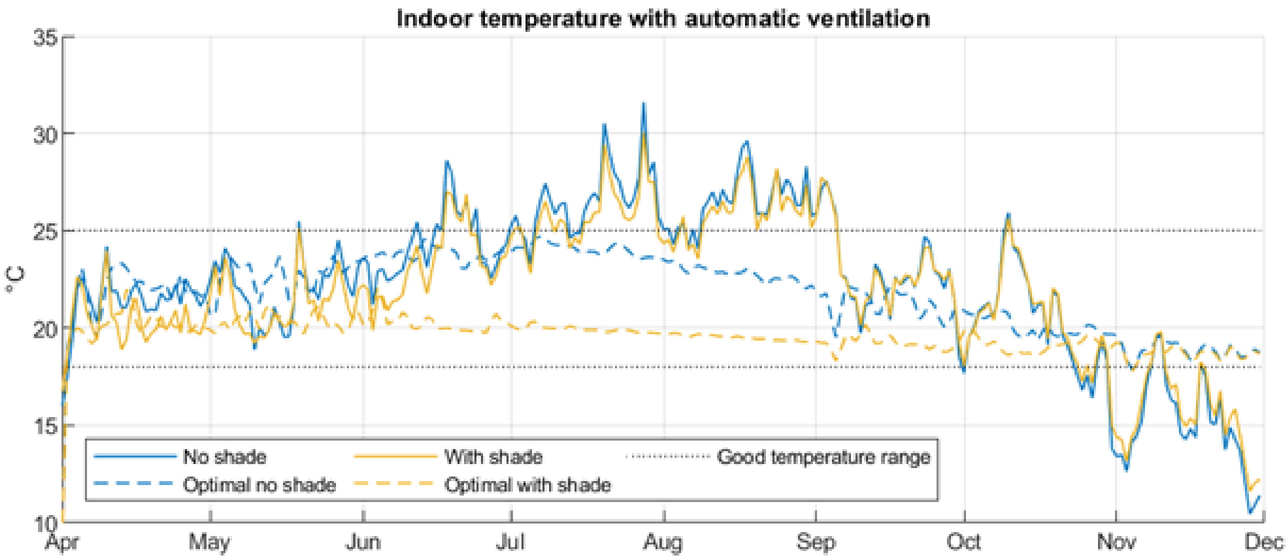


Figure 2.7 *Indoor and optimal temperature, with and without shading, for the scenario of automatic ventilation.*

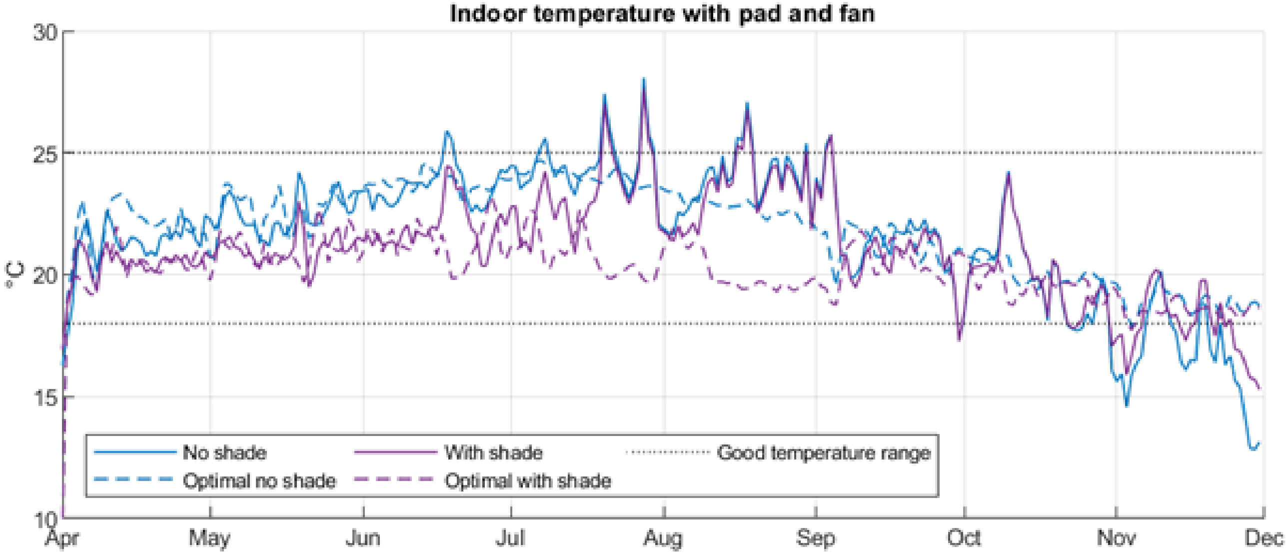


Figure 2.8 *Indoor and optimal temperature, with and without shading, for the scenario of pad and fan cooling.*

In terms of water use, the pad and fan scenario had the highest water consumption (transpiration and colling), and the air conditioner scenario had the lowest water consumption, among the scenarios where cultivation lasted throughout the summer (Figure 2.9). With pad and fan cooling, less water was needed for irrigation due to lower temperatures, but more water was needed for cooling. With air conditioning, water that was regained by the cooling mechanism through condensation could be used back in the irrigation system. Shading also reduced the water use by reducing transpiration.

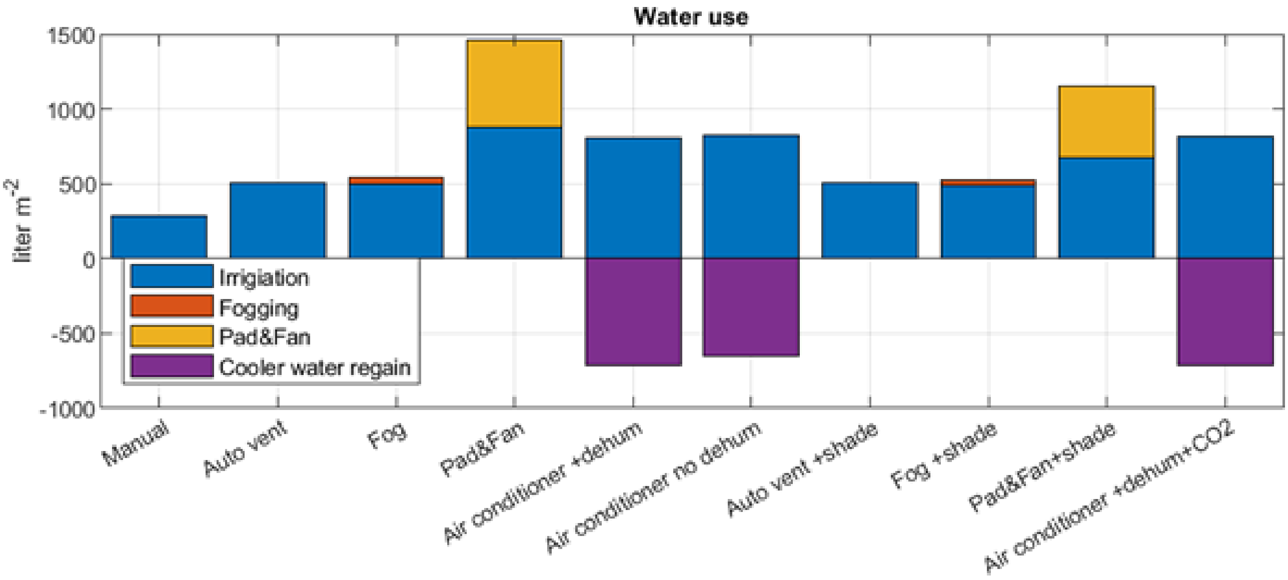


Figure 2.9 *Water use for chosen summer cultivation simulations.*

A big range was observed in terms of potential yield and crop life (Figure 2.9). In most cases, harvest began about 8 weeks after planting. When air conditioning was used to control humidity, the greenhouse was colder and the first harvest was delayed by 2 weeks. With manual control, the crop died after 2 weeks of harvest, with only 1.2 kg/m^2 of yield. With automatic ventilation (with and without fogging), the crop survived 4 more weeks, and reached 4-5 kg/m^2.

Shading helped to avoid too high temperatures and therefore resulted in a prediction for higher potential yield: in the case of automatic ventilation with shading (with and without fogging), the crop survived until the middle of August (1 month longer then without shading), and reached a yield of 8 kg/m². In the case of pad and fan cooling, shading increased the predicted potential yield from 27 kg/m² to 31 kg/m². It should be noted, however, that it is expected that shading will cause issues with the crop balance. Therefore, it is unclear whether shading will actually bring these predicted benefits.

For the case of air conditioning, the predicted yields are 8-10 kg/m². The reason for these low yields is low CO_2 concentration in the greenhouse: with air conditioning, the windows are completely closed and very little air comes into the greenhouse. The result is a low CO_2 concentration in the greenhouse and slow crop growth. Including CO_2 injection together with air conditioning raises the potential yield to 45 kg/m².

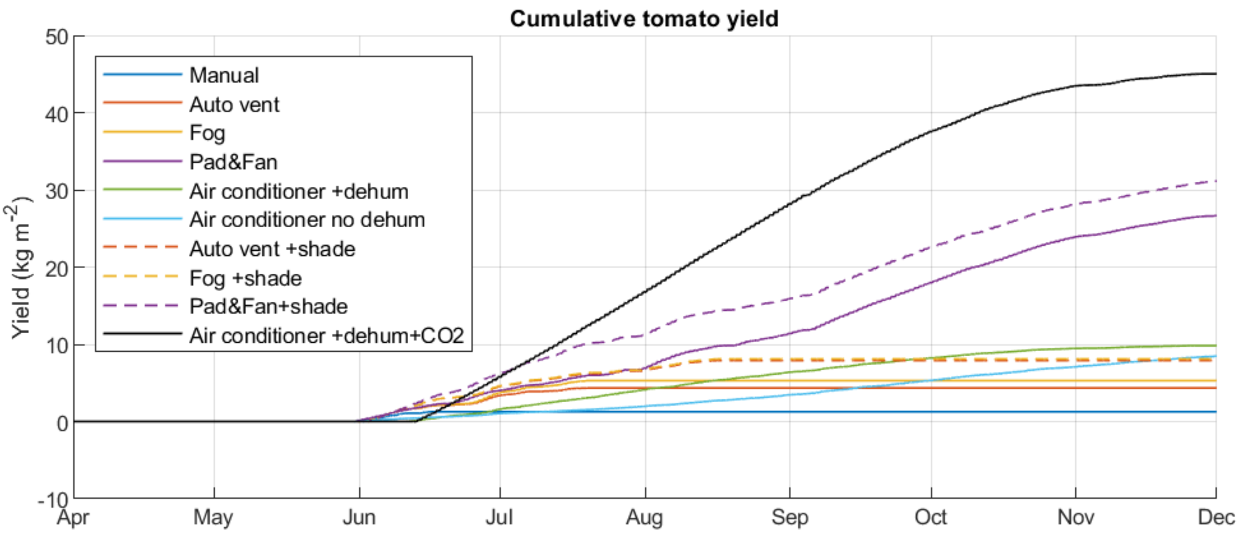


Figure 2.10 *Potential yields for chosen summer cultivation simulations.*

In summary, the technical details of some chosen simulated winter cultivation scenarios are given in Table 2.2.

Table 2.2

Technical details of simulations for summer cultivation of tomato.

	Variant 1 Manual ventilation	Variant 2 Automatic ventilation	Variant 4 Automatic ventilation + shading	Variant 6 Automatic ventilation + fogging	Variant 7 Automatic ventilation + fogging + shading
Planting date	April 1	April 1	April 1	April 1	April 1
First harvest	June 2	June 1	June 3	June 1	June 3
Last harvest	June 18	July 20	August 16	July 20	August 16
Ventilation and ventilation area	Manual, 5%	Automatic, 15%	Automatic, 15%	Automatic, 15%	Automatic, 15%
Screens	-	-	Shading screen	-	Shading screen
Cooling	-	-	-	Fogging, 200 g/m^2/hour	Fogging, 200 g/m^2/hour
Potential total water use (litres/ m^2)	290	507	503	540	526
Electricity use (kWh/m^2)	-	-	-	-	-
Potential yield (kg/m^2)	1	4	8	5	8
Comments			- Crop balance issues: risk of a stretched and vulnerable crop		- Crop balance issues: risk of a stretched and vulnerable crop

	Variant 8-Automatic ventilation + pad and fan	Variant 9 Automatic ventilation + pad and fan + shading	Variant 10- Air conditioning, no dehumidification	Variant 11- Air conditioning with dehumidification	Variant 12- Air conditioning, dehumidification, CO_2 injection
Planting date	April 1	April 1	April 1	April 1	April 1
First harvest	May 31	June 3	May 31	June 11	June 13
Last harvest	December 1	December 1	December 1	December 1	December 1
Ventilation and ventilation area	Automatic, 15%	Automatic, 15%	Automatic, 15%	Automatic, 15%	Automatic, 15%
Screens	-	Shading screen	-	-	-
Cooling	Pad and fan, 100 m^3/m^2/hour	Pad and fan, 100 m^3/m^2/hour	Air conditioner, cooling capacity 700 W/m^2	Air conditioner, cooling capacity 700 W/m^2	Air conditioner, cooling capacity 700 W/m^2
CO_2 injection capacity	-	-	-	-	100 kg/ha/hour
CO_2 injected	-	-	-	-	11 kg/m^2
Potential total water use (litres/ m^2)	1465	1154	176	95	95
Electricity use (kWh/m^2)	17	23	290	367	371
Potential yield (kg/m^2)	27	31	8	10	45
Comments	- High risk of disease due to high humidity	- High risk of disease due to high humidity	- High risk of disease due to high humidity	- Maintaining good crop balance is a challenge	- Maintaining good crop balance is a challenge

3 Greenhouse construction

3.1 Greenhouse construction and climate

Greenhouses intend to protect crops from extreme climatic conditions like heavy rainfall, too cold or too warm conditions or a too high or too low humidity. Simple greenhouses have generally few and manual options to regulate the climate, whereas more high-tech greenhouses have more options to regulate the climate and climate can generally be regulated automatically based on climate settings and sensors.

In the Algerian climate ventilation is a very important issue in particular in summer. Traditional greenhouses (Figure 3.1) have limited openings for ventilation and have to be regulated manually.

Figure 3.1 *Traditionally used single tunnels face a lack of ventilation capacity. Mostly only at front and rear end, sometimes a slit or hole is made.*

Manual opening and closing of the ventilation openings in traditional tunnels is laborious and takes only place a few times per year, while plants do like a constant climate. To create a more optimal ventilation, mechanical opening and closing is recommended (Figure 3.2 and 3.3). This can be realized in a greenhouse with vertical side walls with ventilation openings, where opening can be done daily (manually) or more frequently (electrical) when connected to a simple (climate) computer (Figure 3.2). A tunnel with vertical side walls makes it also possible to grow with the high wire system, see chapter Cultivation, leading to much higher production levels.

Figure 3.2 *Increasing the ventilation capacity by opening the side wall is more efficient. Opening can be done manually or electrically (Figure 3.3). Insect netting is required.*

Figure 3.3 *Sidewall ventilation is useful for single span houses and multispan houses up to 5 spans. Use anti insect netting to prevent entry. Use an electro motor to roll the side wall (green circle).*

Length of the greenhouse is also important for the effective ventilation capacity. In Algeria often the single tunnels have a length of 50 m. In summer this is too long. A length of 30 m instead of 50 m length, doubles the ventilation capacity (m^2 opening per m^2 ground area).

Mechanically opened windows in the roof are even more efficient than sidewall ventilation (Figure 3.4). In the Netherlands, greenhouses require less ventilation than in Algeria and greenhouses often have a limited number of roof windows as the climate is much cooler. In Algeria it is proposed to have a continuous window opening as shown in the left two pictures in Figure 3.4.

***Figure 3.4** Examples of rooftop ventilation. Left: the construction of a double roof ventilation. In the middle the ITCMI (Algerian research institute) greenhouse with roof and side wall ventilation; on the right the wide span with continuous ventilation.*

***Figure 3.5** Comparison of two type of greenhouses with a length of 30m in Lebanon. Besides on the picture a rainwater catchment tank connected to the greenhouse gutter, a sluice for entering the greenhouse to avoid entry of pathogens.*

Passive cooling by means of ventilation openings may not be sufficient in hot climates. Pad and fan systems may be used for additional cooling but fans demand much energy (Figure 3.6). Screens are an alternative and additional way to control temperatures. However the ventilation rate reduces with about 50% (right). Moreover, a lower radiation lowers the optimal temperature for crop growth, which means that with insufficient cooling, the crop may grow out of balance and become weak. Combination of screens and fans might be an option.

***Figure 3.6** Additional options for climate control. Left Pad and Fan system. Right screens.*

Young plants in particular are very vulnerable for climate conditions and the regulating effects of a full grown crop on the greenhouse climate is lacking. A temporary transparent liner to decrease the loss of heat during cold nights can be used (Figure 3.7). Cheap heating solutions are also possible like the use of water filled hoses which are heated during daytime and release the heat during the night.

Figure 3.7 *Options for climate control in young plants. In (sunny) winter climate, when plants are young, it might be useful to hang a transparent liner to decrease the loss of heat during cold nights (left). Cheap heating solution is the use of water filled hoses which are heated during daytime and release the heat during the night (middle and right).*

Several options exist for heating the greenhouse in winter conditions. For incidental use, in small compartments, a small gas burner may be used (Figure 3.8). For larger greenhouses a central heating system is required.

Figure 3.8 *Small compartments (for propagation) might be heated with a small gas burner (left). A coal burner is placed outside the greenhouse (middle). Water filled pipes are used for the transport in to the greenhouse. In the Netherlands these pipes are also for internal transport (pipe-rail system). The water is heated with natural gas.*

4 Interior design of the greenhouse

Not only construction but also the interior design and the cultivation methods are important ingredients for a high and sustainable yield. In this chapter we will discuss water supply and fertilization, soil and artificial growing media, propagation and cultivation methods

4.1 Water

4.1.1 Water sources

Water is essential in volume and in quality. Several water source might be used (Figure 4.1). In the Netherlands we start with the mandatory use of rainwater. Rainwater is preferred above all other sources as it has a low EC and does not contain pathogens. However as the amount of rainwater is often not sufficient, there needs to be a second source available. In the Netherlands groundwater/well water is often used as an additional source of irrigation water. In the western part of the country, the EC of the groundwater is often too high (5-10 mS/cm) and mostly reverse osmosis is used to get a good quality water. In the eastern part, where there is less influence of the sea, bore hole water can often be directly used (EC < 1.5 mS/cm).

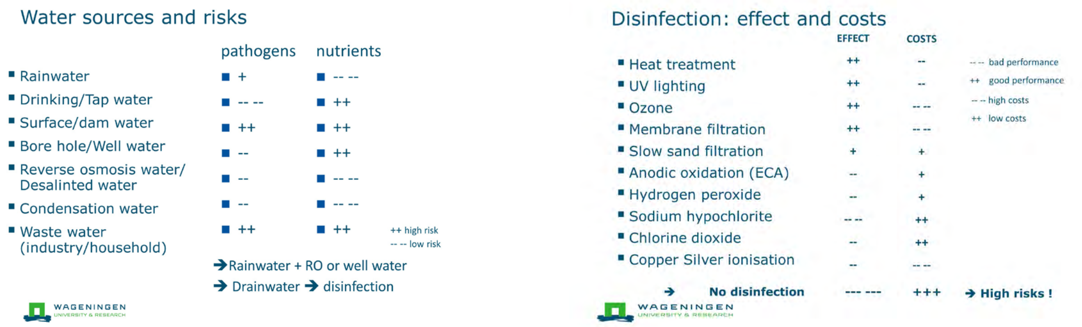


Figure 4.1 *Qualitative aspects of various water sources (left) and disinfection methods (right).*

Rainwater collection from the greenhouse cover is rather easy and can also be done when single tunnels are used (Figure 4.2). If the greenhouse has higher side walls and a rainwater collection gutter can be constructed, collection is simple. The result is a qualitative good quality supply water. Larger companies make use of tanks or basins (Figure 4.3). Tanks are mostly used at smaller volumes (less than 2000 m³). In the Netherlands storage of 500 m³/ha is mandatory, 1500 m³/ha is recommended. In Algeria it is important to realise at what moment the rain is falling and when it is needed for the plants and where storage is possible (in tanks below the greenhouse, in basins beside the greenhouse, in tanks within the greenhouse). The other water source should be available in the dry period of the year.

Figure 4.2 *Rainwater collection in single tunnels (left, middle) and via a rainwater collection gutter (right).*

Figure 4.3 *Storage of water from larger companies in basins (left, middle) and tanks (right).*

In the greenhouse the water is generally supplied to the crops by drippers. Various type of drippers are used like in-line drippers, pressure compensated drippers with tubes, capillaries, tubes with pressure reducing nozzles (Figure 4.4). Our recommendation is to use pressure compensated nozzles with tubes and peg to place the drippers at the right location with a capacity of 2 L/h (Figure 4.4).

Figure 4.4 *Examples of drip irrigation; left in-line drippers, middle left tubes with pressure compensated drippers (most used now) with reducing water pressure either in red circle or in blue circle, middle right 4 drippers at one exit, capacity per dripper is important, right planting the 6 week old plant on stonewool substrate and placing the peg of the drippers at the plant.*

4.1.2 Open and closed systems

A soilless growing system can be open or closed. In an open system surplus water given to the plant is flushed to waste, while in a closed system the surplus water will be disinfected and reused (Figure 4.5). Another option is to use the surplus water in another greenhouse with another crop (no similar pathogens).

The advantage of a closed system is that the water use (L water/ kg product) is much lower than in an open system. Moreover, less fertilizers are needed as they are partly reused. Finally pollution of surface water and ground water with nutrients and pesticides is avoided.

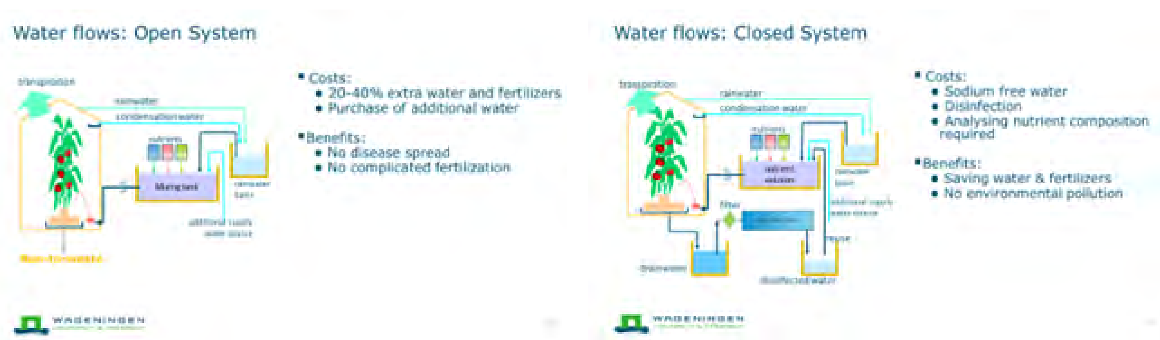


Figure 4.5 *Schematic view of an open and closed soilless growing system.*

In the Netherlands it is mandatory to recirculate the nutrient solution to avoid pollution of surface waters. No discharge of nutrients and in the water circulating remnants of pesticides (PPPs = plant protection products) are allowed to be discharged to the surface water. Consequently all you supply to the system has to be taken up by the plant or broken down in the circulating water (Figure 4.6).

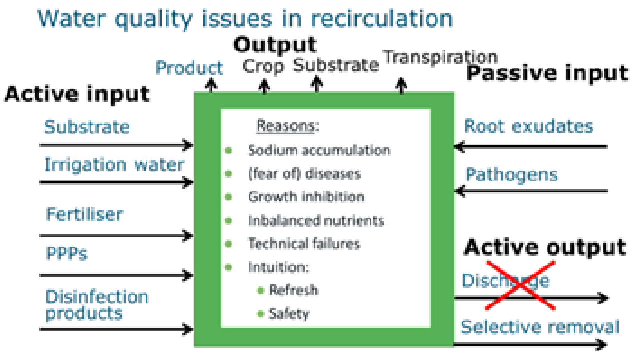


***Figure 4.6** Inputs and outputs of the circulating water system in a greenhouse*

The disadvantage of a closed system is that it requires equipment to purify the water and to adjust the nutrient composition of the irrigation water. This involves higher costs and skills to operate the greenhouse. Moreover the construction is more extended and complicated (Figure 4.5) including collecting troughs and pipework, a pump to bring the drain water to the central water unit, collection tanks, filtering (Figure 4.7, 4.8 and 4.9) and disinfection equipment and more appropriate fertilizer dosing equipment.

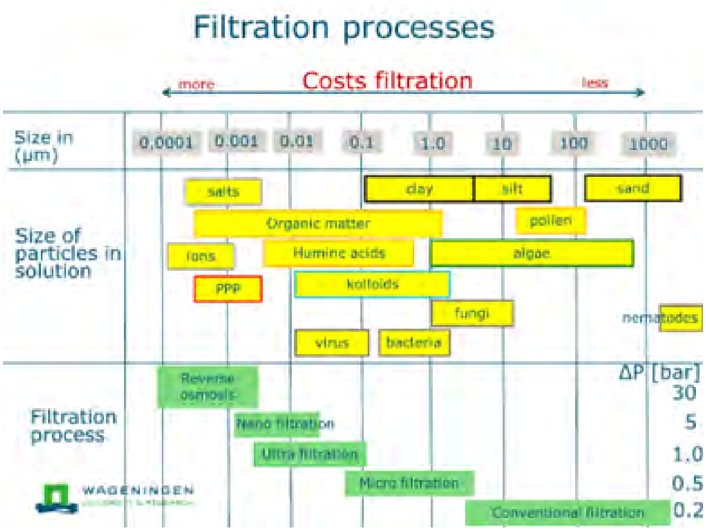


***Figure 4.7** Overview of filtration methods used in greenhouse horticulture.*

Conventional filtration

Type	Separation (µm)	Filter rinsing water
Bow screens	150-500	0
Drum-filter	25-60	0
Sand filter	25-50	2-5% of incoming flow
Flat bed filter	20	0
Screen filter	10	< 1% of incoming flow

Figure 4.8 *Conventional filtration methods are widely used to eliminate coarse particles.*

Figure 4.9 *Reverse osmosis is used to eliminate salts (left), a sand filter to eliminate course particles (middle), always install water counters to register and to know what you are doing (right).*

4.1.3 Fertilisation

Supply of plain water hardly takes place when growing in substrate. Mostly water and fertilizers are given at all irrigation events during the entire growth of the year. The buffer in the substrate is small and, consequently, it has to be topped up frequently. Supply of water and nutrients takes place between 5 and 20 times a day which is much more frequent then in soil cultivation. Special equipment should be present (Figure 4.10). Concentrated (100 times) stock containers are filled with calcium nitrate and, if available ammonium nitrate, and iron chelate for the A-tank. In the B-tank the other fertilizers are put together such as potassium nitrate, magnesium sulphate, potassium sulphate and mono potassium phosphate. If fertilizers from A and B tank are mixed in that high concentrations, precipitation develops in your pipework rapidly leading to clogging of the entire system. Instead, a computerized dosing unit brings fertilizers from the A and B container in the same volume into the mixing tank to be mixed with (drain)water to the right EC level and pH(setpoint in computer). EC and pH are controlled to the appropriate values. For pH, addition of diluted nitric acid is most convenient to a pH of 5.5-6.0. Use of mix fertilizers (15-15-15) and urea should be avoided. The number of A and B tanks can be increased depending on the number of crops with their own nutrient solution. From the mixing tanks the nutrient solution is pumped to day storage tanks, their number depending the number of compartments.

Figure 4.10 *Fertilizer application as it is mostly organized (left), dosing units right.*

In case of recirculation the drainwater coming from the plants should be disinfected (Figure 4.5). In Figure 4.11 two of the most used methods are described. In all cases the drain water from the substrate (1) is collected into a recatchment tank (2). From there it is pumped to the drain water storage tank (3) and in case of heat treatment into unit 4. The solution is pumped with temperature T1 (about 17-25 ºC) into heat exchanger 5 and preheated to T2 (70-80 ºC). In heat exchanger 6 it is further heated to T5 (85-97 ºC) by an external heat source (boiler, 7) which has an incoming temperature of T3 (95-105 ºC) and an outgoing temperature T4 (85-95 ºC). The water is kept at temperature T5 in unit 8 for an exposure time of about 30 seconds and cooled down to temperature T6 (22-30 ºC) and stored in clean water tank 9 to be mixed with fresh water and nutrients for watering the plants.

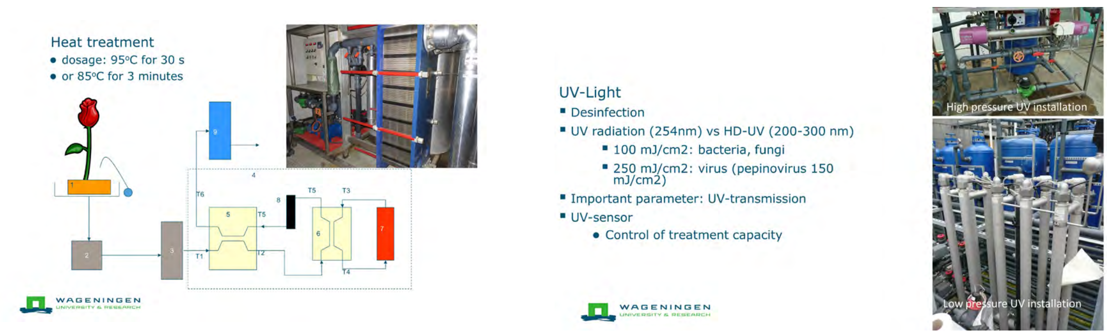


Figure 4.11 *Most used methods to eliminate pathogens from drainwater.*

4.2 Propagation

Young plants in particular are very vulnerable to climate conditions, and the regulating effects of a full grown crop on the greenhouse climate is lacking. On option to increase production is to start with a bigger plant. So it stays longer in the propagation stage. Below a short description of the process (Figure 4.12, 4.13 and 4.14).

Figure 4.12 *An example with stonewool, sowing in trays in plugs (left), spacing them to the 10x10cm blocks (middle) and supporting the plants with a stick and clip (right).*

Figure 4.13 *Here grafted plants (left), a bit bigger ready for transport (middle: wrong; right: good) to grower to be planted on final destination.*

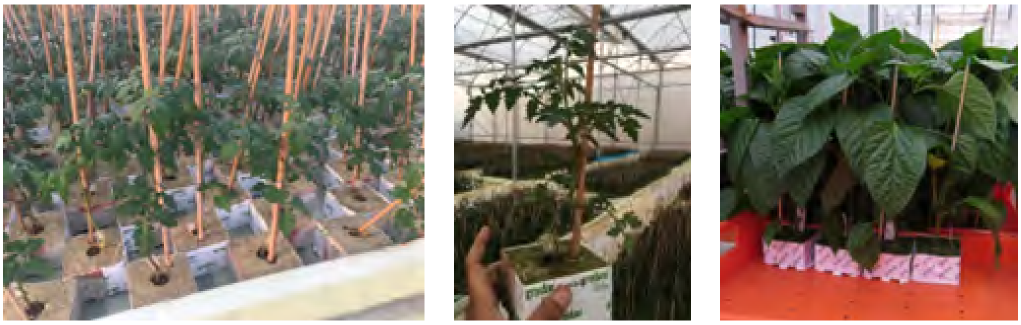


Figure 4.14 *The about 5-6 weeks old tomato plant (left and middle) and 7 weeks sweet pepper plant (right) ready to be planted.*

4.3 Growing system

Another important choice is the selection of the growing system. A general approach for greenhouses in high-tech horticulture is given in Figure 4.15. As can be seen in the figure, a solid substrate is preferred for tomato, cucumber and strawberry, and a hydroponic system is recommended for lettuce. The preference of substrate over soil is not followed in all countries. The advantage of substrate is a lower occurrence of soil bound diseases, better options for recirculation and higher growth. In the EU, growing in soil is mandatory for organic certification.

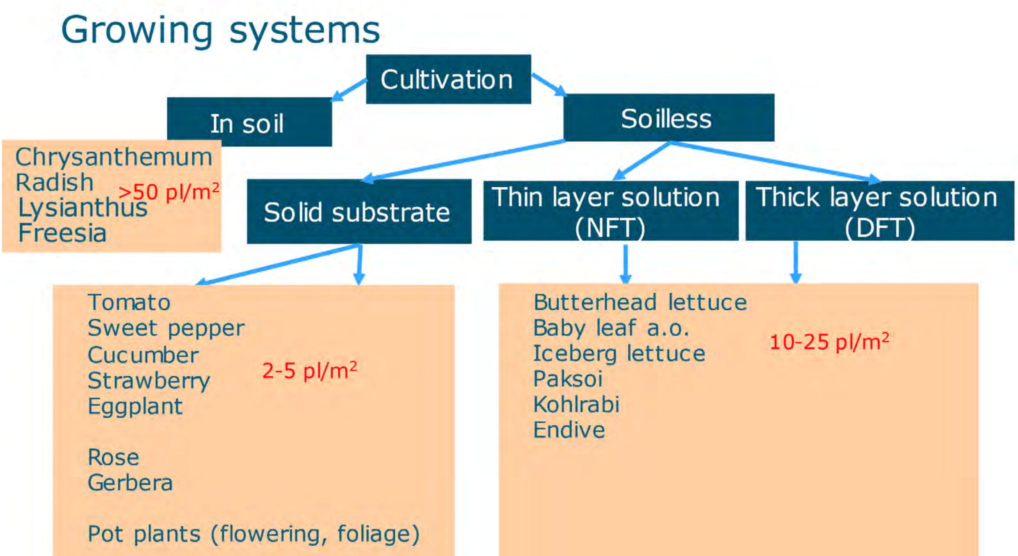


Figure 4.15 *Crops per type of growing system.*

4.3.1 Tomato and cucumber

Tomato, cucumber and sweet pepper are mostly grown in a similar growing system, with a similar plant density (2-3 plants per m^2). Mostly slabs are used but bags with a loose substrate may be used as well (Figure 4.16 and 4.17). Cucumber cultivation is changing from an umbrella system to a high wire system, which requires more frequent labour input. Mostly 2 or 3 cucumber cultivation cycles per year are realized in the Netherlands, with the crop changes around December, April, and July. For tomato and sweet pepper, 1 cycle is the standard (December planting, last harvest in November for unilluminated greenhouses). Due to the current high energy prices, planting dates this year will be a bit later than usual.

Figure 4.16 *Cheap soilless systems with plants in a bag filled with a loose substrate (coir or peat or another locally available substrate). Bags can be black or white, in winter black has an advantage, in summer white.*

In any case, preparing the system starts with levelling the soil. Laser equipment is recommended to level it smoothly. In Figure 4.16 you can see some problems if it is not done correctly. Covering the soil with black or white liner is an option. In the Netherlands a white liner is chosen because of light reflection. In Mediterranean countries a black one might be chosen to collect some heat during daytime which is redelivered to the air during the night. Troughs can be laid on the ground but also be placed on stages or hanging on the construction (see Figure 4.16, 4.17). The latter are more expensive, especially metal coated troughs.

Figure 4.17 *Some examples of system with slabs. Left: System with a black trough with a grid upon which a slab is lying. This system ensures that drain water from one slab does not contact the roots of a next slab to avoid spreading of pathogens within the row. Middle: Not properly levelled ground gives an overflow at certain low locations (loss of water with fertilizers and wet slippery spots for workers). Right: In the bag system the bags are standing in the trough and are blocking the drain flow. This results in root and algae growth in the trough and risk to spread fungal pathogens (middle). Here bags can be placed upon a block to realize a better flow.*

4.3.2 Strawberry

For strawberry a uniform irrigation just after planting is important (Figure 4.18). It means that the lay-out in the greenhouse must be carefully done. Older systems make use of the levelling off the ground with ridges. Modern systems make use of systems on stages or hoisted on the greenhouse construction.

Figure 4.18 *Above: a heterogeneous lay-out of a strawberry system at which not all plants receive the same water volume. It results in dying of plants directly after planting.*

As strawberry is planted with a mass of roots it is mostly planted in a loose substrate as peat or coir. These substrates have a high water content, which strawberry prefers. Different types of bags and containers are used, but also slabs filled with coir can be bought (Figure 4.19).

Figure 4.19 *Coir bags with heterogenous irrigation (left), polystyrene containers (middle left), two layer system (middle right), drain collection (right).*

In Figure 4.19 there is a fixed 2-layer system, in Figure 4.20 the troughs are movable. If no labour is required, all troughs are hanging horizontally in one line. If labour has to be done, half of the troughs are hoisted upwards while the other half is lowered to improve labour quality.

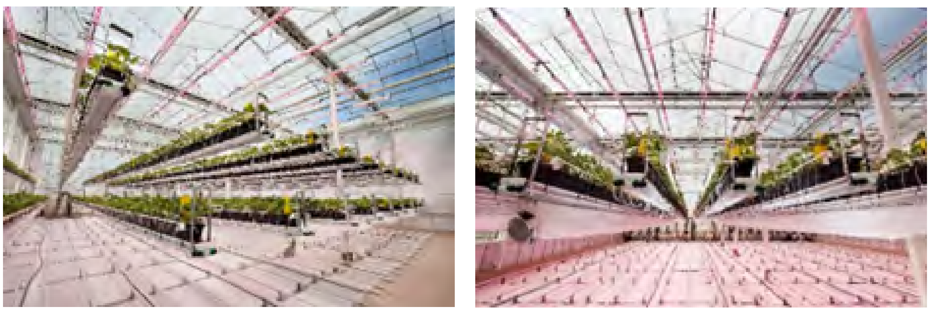


Figure 4.20 *Strawberry in a movable system with artificial LED light.*

4.3.3 Lettuce

All types of lettuce are mostly grown in a hydroponic system; either nutrient film technique (NFT) or deep flow technique (DFT). Properties are explained in Figure 4.21 and 4.22.

Figure 4.21 *Properties of NFT and DFT lettuce system.*

The systems can be fixed, all plants stay at the same place, or movable. In a movable system there is one place to plant and another for harvesting and plants move through the greenhouse. One or the other has pros and cons. However the most flexible system is also the most expensive one.

Figure 4.22 *An NFT lettuce system from NGS (left), DFT with floating panels (middle), multi-layer system (right).*

For commercial production in greenhouses a one layer system works good. A multi-layer system without artificial light is impressive for visitors and consumers, but is not practical for the grower as the uniformity between vertical layers disappears rapidly realizing much more labour per m^2.

4.4 Cultivation

In this chapter there is a special focus on the relation between greenhouse design and the cultivation method of tomato and cucumber.

In a traditional tunnel a standard up-and-down training system for the plants is mostly used (Figure 4.23). The horizontal wire is at 2-3 m height. Reaching the wire the top of the plant is guided via hooks or via the wire downwards again. Growing downward is not optimal and there is a certain loss of production and quality because of the downward growth.

High wire system for tomato
The high wire training system for tomato is especially suitable in higher greenhouses. The horizontal support wire should hang at 3.5 m height, while hooks with strings are hanging at this wire (Figure 4.23 and 4.24). After planting the plant grows after twisting into the string towards that 3.5 m. Next stage, the hook with the string will be unwound to lower the plant while at the same time the hook is moved forward along the wire for about 30 cm. This process will be repeated each week. The high wire system makes it possible that all plant heads are always hanging in the light and perform optimally. A yield increase from 10 to 30 kg/m^2 might be possible if having a long season. Each week a tomato plant produces one truss, if you have a growing season of about 30 weeks, 30 trusses might be the result. Depending on the size of the tomatoes, about 30 kg/m^2 might be feasible. For optimal quality the long stems, after cultivation of about 15 m, have to be layered horizontally without touching the ground (leading to wet stems and risks for fungal diseases). One stem is layered backward, the next one layered forward in the path beside, realizing a carrousel of plants (Figure 4.24). Deleaving is another important activity during cultivation: each week take off the leaves up to the ripening truss, just do it before harvesting starts due to visibility of ripe fruits.

Several devices might help the training of the tomato plants to improve quality (Figure 4.25). First, hooks might be used if twisting into the string is not working appropriate, which is especially the case if the main tomato stem is very thick in Spring. Another hook is used to avoid kinking of the truss stem.

Figure 4.23 *Traditional tomato cultivation in single tunnel (left), a high wire system with a young tomato crop (middle) in a greenhouse with vertical side walls, harvesting well visible tomatoes (right).*

Figure 4.24 *High wire or layering training system for tomato. Left support for stems, middle the carrousel at the end of the path, right the hooks on the wire in the top of the greenhouse.*

Figure 4.25 *Help devices against kinking (left), supporting the stem (in brown-red) (middle left), a lorry for high wire activities (middle right), looking through a high wire crop after 10 months (right).*

Cucumber can also be grown according the high wire system (Figure 4.26). However this is much more challenging compared to tomato. As the cucumber plant growth faster, work has to be done in time twice a week. Twice a week twisting in the head of the plant and layering the main stem, if it is not feasible, don't start to avoid a big mess. If doing well more than 60 kg/m^2 per year (2-3 cultivation cycles) can be achieved.

Figure 4.26 *Cucumber at the high wire system.*

5 Economics of the greenhouse options in relation to market prices

5.1 Commercial greenhouses

For the various simulated greenhouse designs, as simulated in Chapter 2, economic calculations were made. Calculations were done for 6 situations without cooling or heating and cultivation in spring/summer and autumn (variant 1 to 4, 6 and 7). One with heating in a winter cultivation (variant 5) and five variants for summer cultivation (April-December) with cooling. As the price levels of horticultural equipment in Algeria were not known, the results are based on Dutch assumptions and can vary if applied in Algeria. Moreover, prices are anyhow subject to changes due to scarcity and inflation.

To make these calculations the following costs for the infrastructure were used. For all these costs a depreciation over 15 years has been assumed.

Table 5.1
Cost of infrastructure (€/m²).

Design Element	Large greenhouses >1ha	Small greenhouse (0,5 ha)
Multispan greenhouse with manual roof vents	37	
Single tunnel		10
Automatic roof vents	5	
Heating pipes incl distribution	8	
Boiler	6	10
Air burners	2	2
Energy screen	10	
Shadow screen	9	
Fogging system	6	
Pad & fan system	6	
Rainwater collection	5	
Drip irrigation	2	
Throughs	6	
Dosing unit	2	
Air conditioning	200	
Humidity control	6	
CO_2 dosing	2	
Disinfection unit	4	
Drain water storage and pipes	1	

Table 5.2

Overview of the investments of the greenhouse variants for cultivation of tomato on soil, substrate without re-circulation of water and substrate with recirculation of water and production levels on substrate.

Variant	Name	Investment Soil cultivation (€/m²)	Investment soil culativation+ water storage	Investment Substrate cultivation without recirculation (€/m²)	Investment Substrate cultivation with recirculation (€/m²)	Production (kg/m²)
1	Control, Standard multispan (>1 ha) with plastic cover and manual ventilation control, 5% window opening (Canarian type). No screens, no heating. Production season from April-June and Sept-Nov	37	41	55	60	5
2	Same as control, with automatic ventilation and 15% window opening. Production April-July and Sep-Nov	42	46	60	65	7
3	Energy screen in winter. Production Apr-Jul and Sep-Dec	52	56	70	75	8
4	Shadow screen in summer. Apr-Aug, Sep-Dec	51	55	69	74	11
5	Heating with pipe heating, automatic ventilation, energy screen. Sep-July	65	69	84	88	39
6	Fogging in summer. Production April-July and Sep-Nov	48	52	66	71	8
7	Fogging and shading in summer. Production April-July and Sep-Nov	57	61	75	80	11
8	Pad and fan. Production April-Dec	48	52	66	71	27
9	Pad and fan with shading. Production Apr-Dec	57	61	75	80	31
10	Air conditioning with no dehumidification control. Apr-Dec	251	255	269	274	8
11	Air conditioning with dehumidification control. Apr-Dec	257	261	275	280	10
12	Air conditioning with dehumidification and CO2 injection. Apr-Dec	259	263	278	282	45

For the annual variable costs a price for gas of 0.35 €/m^3 and for electricity of 0.032 €/kWh have been assumed. For substrate a cost of 0.01 €/m^2 has been estimated based on a use of 10 liter of substrate per m^2 and a price of 80 €/m^3. Costs of water were set at 233 DZD (1.6 €) per m^3 (ENSA) and for liquid fertilizers on 250 DZD (1.3 €) per kg. Costs of labor and plant protection products have not been taken into account.

The investments (Table 5.2) range from 37 €/m^2 for a greenhouse with manual ventilation and cultivation in soil to 282 €/m^2 for a greenhouse with air conditioning and cultivation in substrate and recirculation of water. Estimated production levels range from 5 kg/m^2 to 45 kg/m^2 for cultivation in substrate. As presented in Chapter 2, the production levels for a spring/summer and autumn cultivation are limited without the use of cooling or heating.

The costs per kg of produced tomato (Figure 5.1) are the highest in the variants with air conditioning but without addition of CO_2 (variants 10-11) as the production rates are low and not compensated by the high investments. The variants without heating or cooling (variants 1-4, 6-7) also lead to higher prices per kg of tomato due to the low production rates and the still considerable investments and running costs of water and fertilizers. The lowest cost per kg product are estimated for the summer cultivation of tomatoes with cooling with pad and fan (variants 8-9 - 0.25 to 0.28 €/kg). However, recall from Chapter 2 that in these cases, there were multiple issues predicted, including high humidity (and therefore high risk for disease) and issues with crop balance. Also for the case of shading, it is unclear whether shading will actually bring the predicted benefits due to crop balance issues. The use of air conditioning in combination with CO_2 injection would lead to the highest summer production (assuming issues with disease and crop balance could be handled), but at higher costs (variant 12 - 0.76 €/kg). However, this option is associated with an electricity use of 371 kWh/m^2/year. When the electricity is generated based on natural gas this leads to a CO_2 emission of 240 kg/m^2/year.

Winter cultivation in a heated greenhouse leads to an estimated price of 0.38 €/kg (variant 5). The indoor climate in the greenhouse is more favorable for growing compared to the summer situation and will most likely lead to lower risks and costs associated to plant protection. The heating will lead to a CO_2 emission of 23 kg/m^2/year.

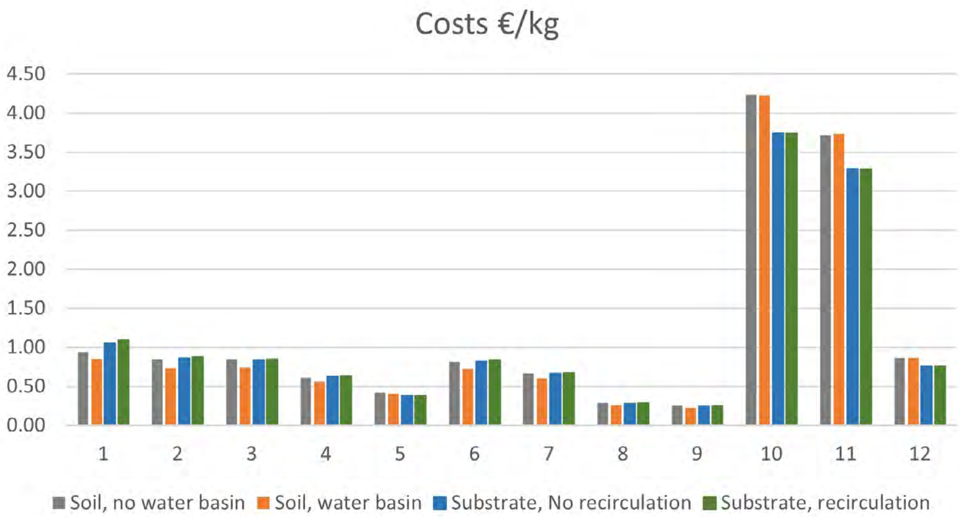


Figure 5.1 *Costs per kg tomato in the various greenhouse variant.*

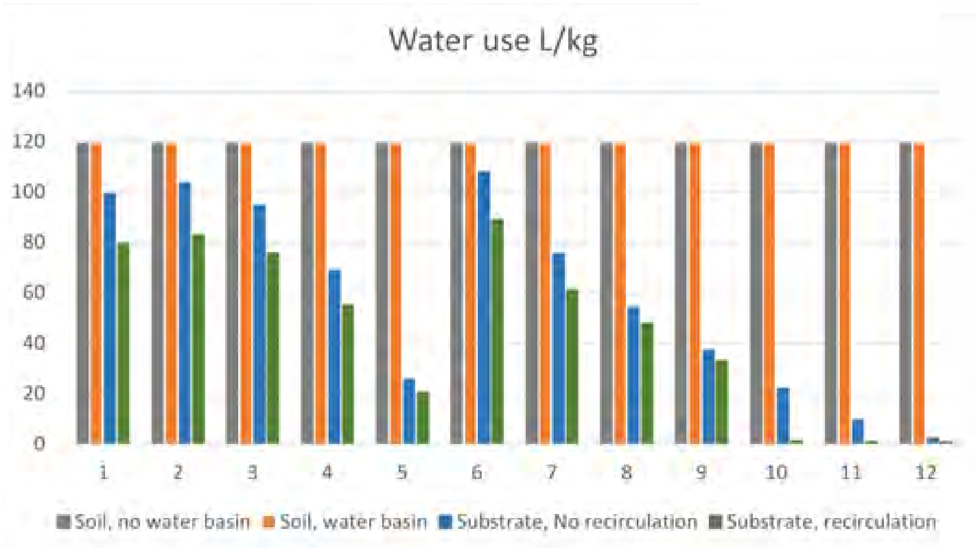


Figure 5.2 *Water use per kg tomato in the various greenhouse variant.*

Water use is high in all soil bound cultivations (120 L/kg) and lowest in the system with substrate and the recirculation of water (Figure 5.2). In winter cultivation with heating, a water use of 21 L/kg can be obtained (variant 5). In the summer situation with air conditioning, water use can be reduced to a couple of liter/kg as the evaporating water can be regained by the air conditioning (variants 10-12).

A water basin (20.000 m^3/ ha) can be used to store rainwater, collected on the roof of the greenhouse during winter. The water use figures above are not corrected for the use of the water basin. In early summer more than 85% of the water for irrigation water can be obtained from the basin (scenario 1 to 7). For the situation with pad and fan, in which cultivation continues throughout summer, only 40-60% can be delivered by the basin. In winter the contribution of the basin is also around 40-60% as the basin will be empty in fall when the cultivation starts.

5.2 Greenhouse at ENSA

A greenhouse at ENSA is not the same as a commercial greenhouse. Normally all technical features have to be applied on a much smaller area. Research facilities will be at least a factor 10 more expensive per m^2 compared to commercial greenhouses.

Our suggestion for the ENSA greenhouse would be (Figure 5.3):
- 4 compartments of 200 - 300 m^2 per compartment.
  - For each crop a compartment
    - Tomato/cucumbers: high wire system on soilless system with pipe heating and 1 or 2 movable screens
      - Heating pipes are also in use for internal transport
    - Lettuce: trough system half on NFT and half on DFT
      - No heating/cooling
      - Shadow screen
    - Strawberry: trough system with long shaped container with coir on stages with drip irrigation; recirculation
- All 4 compartments should have a separated climate control and a separated water and nutrient dosing (EC, pH and composition) via a computer.
  - There is a continuous roof ventilation by computer driven windows
  - There is technically no preference for plastic or glass cover. Plastic will be much cheaper and feasible for Algerian growers. So acceptance of results achieved in these compartments will be easier.
- Rainwater will be collected from the roof and stored. An additional water source is available.
- As visitors will be frequently entering the greenhouse a corridor in front of the 4 compartments is required.
- There is digital data storage of all climate and irrigation data.

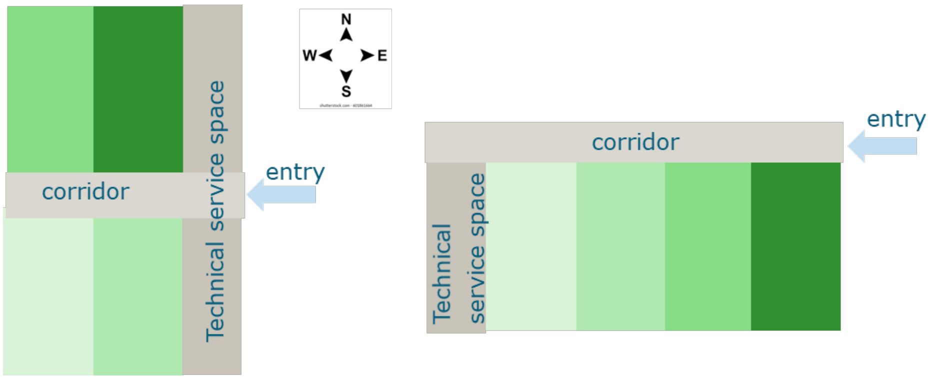


Figure 5.3 *Schematic overview of greenhouse lay-out (examples).*

6 Conclusions and recommendations

The simulations of climate and production and the economic analyses indicate that there are two main options for increased production of tomatoes and similar products like cucumber and sweet pepper. A choice can be made for winter production (September-July) in a heated greenhouse or summer production (April-December) with cooling. The estimated production is fairly similar for both seasons at approximately 40 kg/m^2 for a heated or an air conditioned greenhouse with CO_2 application. The costs are approximately 35% higher in summer due to higher investment costs. Moreover, market prices of tomatoes will be higher in winter compared to summer, making winter cultivation more attractive. All figures are based on an optimal management and no loss of production due to pests or diseases.

An alternative to a high tech greenhouse with air-conditioning is the use of a pad&fan system for cooling. The investment is considerably lower (approximately 50 €/m^2 compared to 280 €/m^2). Production levels are also lower leading to a 50% lower price /kg tomatoes as the system with air conditioning. However, the climate in the pad&fan system is less favorable. Simulated humidity was quite high, leading to higher risks for fungal diseases. It should further be noted, that it is expected that shading will cause issues with the crop balance. Therefore, it is unclear whether pad&fan combined shading will actually bring the predicted benefits.

All system without heating or cooling have much lower production rates (less than 10 kg/m^2) due to the limited length of the growing season (no production from December to April and in July and August) and less favorable temperature conditions during the cultivation periods.

The use of substrate, the recirculation of water and the use of basin for rainwater collection reduces the use of water for cultivation. The greenhouse with air-conditioning leads to the lowest water use as the evaporating water can be recaptured by the air-conditioning. In winter cultivation the water use is higher but still low compared to summer cultivation with a pad&fan system.

The above calculations have been done with tomato as a example crop, assuming a optimal management and no loss of production due to pests and diseases. Similar conclusions might be drawn for cucumber.

Strawberry and lettuce have lower demands for temperature and may be more suitable for cultivation without heating in winter. These crops might also be interesting for smaller growers, who cannot invest in heating or cooling and like to combine an autumn/spring growth of tomato/cucumber with an early winter/early spring cultivation of salad or strawberry.

In summary this may lead to the following constructions:

Tomato/Cucumber
- Commercial practice
  - Small farms (<5000 m^2): 5 span (about 8x30 m, depending local usage) multispan with vertical sidewalls with a continuous roof ventilation and sidewall ventilation (electrical), rainwater collection and storage. No heating or cooling facilities installed, high wire system is present due to a gutter at at least 3.5m.
  - Big farms (>1 ha): multispan with gutter height at 4-5 m to optimally apply high wire system, good climate conditions and a continuous roof ventilation (Figure 3.4), rainwater collection and storage. Heating is installed to grow in winter time via a pipe rail system (Figure 3.8, right) or cooling by air-conditioning combined with CO_2 application for growing in summer time, shadow screens for shadow in summer.
- Research and demo/education (ENSA)
  - A 500 m^2 multispan for high wire system including a continuous roof ventilation with gutter height at 4-5 m, heating via a pipe rail system. To slightly extend the season cooling via screens and or mist installation might be considered (not calculated in this report), rainwater collection and use. Preferably 2-4 compartments of 200-300 m^2. Preferably combined with the lettuce/strawberry compartment of about the same size.
  - Option: use of water filled hoses and transparent plastic cover in winter.

Lettuce/strawberry
- Commercial practice
  - Similar as tomato/cucumber but without heating facilities, screening might be an option.
- ENSA university
  - Similar as tomato/cucumber but without pipe/rail heating facilities, eventually a gas/oil burner; screening might be an option; 1 or 2 compartments besides the earlier mentioned 2-4 compartments (Figure 5.3).

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

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