General Cultivation Manual Jordan

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Report WPR-896

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Referaat
De verandering van low- naar mid- and high-tech kassen en van grond- naar substraatteelt brengt voor iedere tomaten en paprika tuinder veel nieuwe aspecten. Al die veranderingen (geautomatiseerde ventilatie, gebruik van schermen, bemestingsapparatuur, gewasgeleiding) en symptomen (gebrek- en overmaat verschijnselen, nieuwe ziekten en plagen) worden in dit rapport uitgebreid beschreven. Afgesloten wordt met een checklist om regelmatig te raadplegen en om de kans op fouten te minimaliseren.

Abstract
Changing from low- to mid- and high-tech greenhouses and from soil to soilless cultivation require adapted cultivation measures for tomato and sweet pepper. Major differences are the automated regulation of ventilation (opening of windows), radiation (using screens or whitewash), fertigation and irrigation, a high wire plant training system and plant propagation in substrate. All topics are extensively described. A checklist for the grower facing all these new and unknown phenomena is added to minimize the chance on mistakes.

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Summary

Changing from low- to mid- and high-tech greenhouses and from soil to soilless cultivation require adapted cultivation measures for tomato and sweet pepper. Major differences are the automated regulation of ventilation (opening of windows), radiation (using screens or whitewash), fertigation and irrigation, a high wire plant training system and plant propagation in substrate.

Propagation and grafting is extensively described, a good start makes your crop. It is followed by an explanation of various growing systems and why to choose for a system with a solid substrate or for a DFT or NFT system (i.e. leafy vegetables). The focus is put on tomato and sweet pepper for the situation in Jordan, in addition, for all main crops some information is added. As new mid- and high-tech greenhouses are being implemented, the basics of climate control are explained to make reading of graphs and tables in the climate computer easier. The integration of different parameters is also explained, such as the influence of radiation on temperature and relative humidity and its consequence. For example when RH is becoming too low it might be better to let increase the temperature a bit more.

A high wire system (horizontal wire at more than 3m height) requires another approach of crop management. For tomato this is explained in detail and for tomato and sweet pepper a general planning during cropping is given. The change from soil to soilless systems requires a drastic change of the fertilisation. Basic topics about the chemistry are explained, some information is given of the role of individual main and trace elements and the calculation from a nutrient solution (in mmol/l) to a recipe (in kg fertilizer for an A and B stock container) and nutrient disorders are described. Finally basics of integrated pest management are explained and major pests and diseases of tomato and sweet pepper are presented.

At the end of the cultivation the greenhouse has to be emptied and cleaned thoroughly. The steps and hygienic measures that should be taken are discussed.

As there are so many changes and new things to take care a checklist for all topics is added to minimize the chance of mistakes.

The manual at hand originates from the extensive experiences of the authors in The Netherlands, Spain and from projects all over the world. It is adapted for Jordan conditions and for Jordan growers growing tomato and sweet pepper. Nevertheless further adaptation of given setpoints might be needed after extensive built up of experience with the soilless growing system under Jordan conditions.

1 Introduction to the manual

The aim of this manual is to present a general overview of cultivation activities in mid and high tech greenhouses mainly for tomato and sweet pepper in arid and semi-arid regions. The emphasis in this manual will be on cultivation in soilless culture systems, more particularly substrate based systems but cultivation in soil in mid- and high-tech greenhouses will be addressed as well.

Major differences with traditional (soil) growing in low tech greenhouses are listed here and will be discussed:
- Propagation from seed to a young plant to be planted in the greenhouse.
- Automatic regulation of ventilation (window and side opening).
- Automatic regulation of radiation (top shading screen in addition or not to white wash).
- Automatic fertigation via spaghetti drippers instead of in line drippers.
- High wire cropping system (plant management).
- Introduction of integrated pest management (IPM).

Finally, a checklist for the grower is added to show most important (new) topics to be tackled to minimize the chance of mistakes.

2 Propagation

2.1 Propagation medium and plant density

Soil growing starts with 2.5 x 2.5 x 5.0 cm tapering peat mix plugs which are directly transplanted into the soil. As conditions during transplant can be harsh, attention should be paid to hardening the plants before delivery by e.g. reduced irrigation (to raise the EC); copper sulphate spray and/or paclobutrazol (Cortar) just to keep the plants short.

For stonewool systems a plug-slab system or a plug-block-slab system is applied (Figure 1). The plug-slab system starts with a small plant (3-7 cm) which grows in a seedling tray and will not be spaced wider. Planting of the plug is after 20-25 days. The disadvantage is that young and small plants may have more trouble adapting to the differences in climate in the new greenhouse compared with the greenhouse where they were raised.

With the plug-block-slab system a much larger plant (after 35-42d, 20-40cm high) is planted on the slabs at their final location. In the plug stage 500-1000 plt/m^2 are raised from seed, after which plugs are spaced into a dense block phase (100 plt/m^2 for 7 days) and after a further spacing a block phase (14 plt/m^2 for 7 days too). After that blocks are transplanted onto the slabs (ca 2.5 plt/m^2) at their final growing place.

Figure 1 *The stonewool system with, left, Plugs 2x2x2.7 cm, middle Blocks 10.0x10.0x6.5 cm and right Slabs e.g. 120x12.5x7.5 cm.*

For coir a plug-slab or a plug-block-slab system can be used too (Figure 2).

Figure 2 *Round coir plug about 5x5 cm (diameter x height); plugs in tray; coir blocks 10x10x6.5 with stonewool plugs (not recommended, use one type of substrate); coir cultivation system: slabs (133x12x7.5 cm) upon which blocks will be placed.*

2.2 Plant raising

In a number of steps plant raising is explained from seed to young plants, including fertigation. In a number of situations plant raising is done at a specialized company, the propagator, while cultivation is done at the farm. Sometimes growers raise their own plants without making use of a propagator.

Plugs of a suitably fine material are prepared and an indentation to hold the seed is used. Seeds are sown manually or by machine. Covered with 1-2 mm of fine soil and/or vermiculite. After sowing, the plugs are irrigated with a low EC but still with all elements needed (Table 1). Note the EC mentioned is the EC of the nutrients NOT the EC of nutrients and the water used. If the EC of the water is 0.4, the EC values in the table increase with 0.4. After sowing, plugs are covered with light impermeable plastic and kept for a few days at 28°C and 100% RH. As soon as most seeds have germinated the plastic is removed to keep the hypocotyl (stem under the first (seed) leaves) as short as possible.

Below a step by step description is given to irrigate from sowing to planting in the slab. Special care is given on how to prepare a stock solution (meant for use during the entire propagation time) and the various steps to dilute this stock solution.

Step 1. Plugs in tray

Table 1 shows the stages of a plug-block-slab system and an example of settings for EC, shading screen use (hours per day) and temperature. These settings need to be adjusted to create the desired plants, depending on circumstances and experience.

Table 1

Expected[1] settings in propagation (plug and block) and cultivation (slab).

Step Nr.	Time	Material	Density	EC[1] irrigation	EC[1] root zone	Screen[1]	Estim. RH[1]	Estim. T[1]
	In days		Plt/m²	dS/m	dS/m	h/d	%	°C
1-6	Day 0-1	Plug**	500	1.0	1.0	24*	100[2]	28
7-8	Day 2-6	Plug**	500	1.0-2.5	1.0-3.0	24*	30	28
9-10	Day 7-15	Plug**	500	2.5-3.0	3.0-5.0	24*	30	28
	Day 15-22	Block**	100	3.0	3.5-5.0	12-6	80	30
	Day 22-29	Block**	16	4.0	5.0-7.0	6-0	65	32
	Day 29-36	Slab	2.5	2.8	4.0	6	50	32
	Day 36-	Slab	2.5	2.8	4.0	0	50	28

[1] Actual settings are dependent on climate and actual measured data

[2] High RH under the cover

* Shade perhaps by screen-house screen but not too dark

** Usually at propagator

Step 2: neutralising water (Figure 3)

- Based on chemical analysis of the water source, the source water need to be adjusted for pH. Neutralising is needed if more than 0.5 mmol HCO_3 was found in analysis (each additional mmol HCO_3 has to be compensated with 1 mmol of acid (H+).
- Target pH may be pH 5.5-5.7.
- Neutralising can be done with:
  - Nitric acid if available.
  - Sulphuric acid (not over 3 mmol/L; if more is used there comes too much sulphate in the solution).
  - Phosphoric acid may be used but only to the level required by the plants (max 1.5 mmol/L); no overdosing to avoid precipitation!
- The daily quantity of water required will be max 4 L/m^2/d. As with overhead spraying there is a loss of 50%, we calculate a maximum supply of 8 L/m^2/d. Calculate the required quantity per day for all plants irrigated. We advise to store 1-10 m^3 neutralised water at all time. Neutralisation should be done with registration of:
  - Residual treated water already present in the tank.
  - Amounts of raw water added.
  - Amount of acids used.
  - pH measured before.
  - pH measured just after vigorous stirring.
  - pH measured after 24 hours.
- Registration of data to look back later.

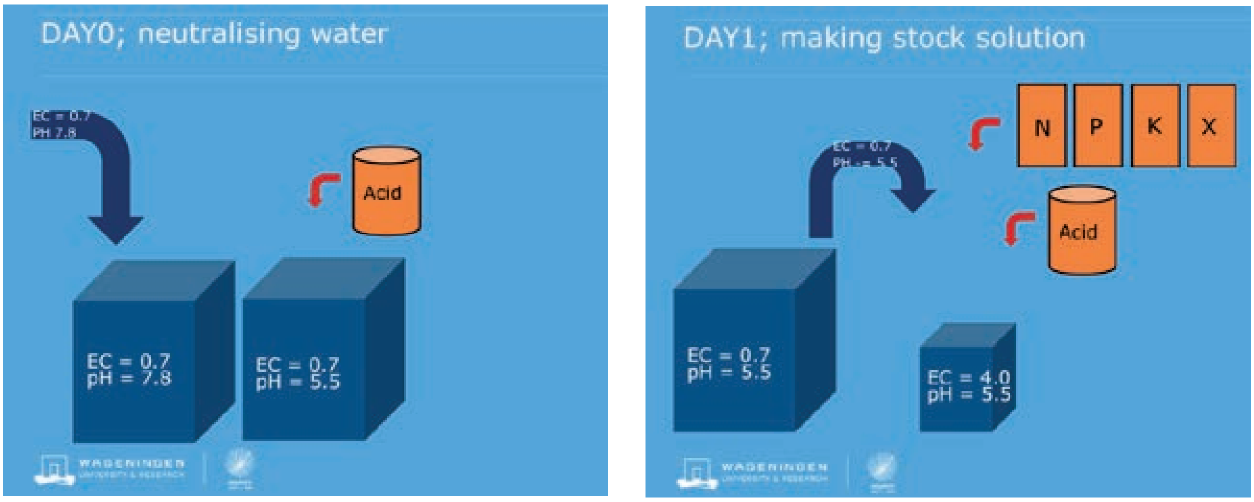


Figure 3 *Step 2 left and Step 3 right.*

Step 3: making stock solution (Figure 3)

- Before starting, a nutrient schedule with calculated amounts of individual fertilisers, including acids, needs to be prepared to realise the concentrated solution in the stock solution tank (EC = 4.0). See Ch 6.3. for more details.
- Filling the stock solution tank (right on drawing) by adding fertilisers to neutralised water. The stock solution is used during the entire propagation period, one starts with irrigating with EC = 1.0 and later it will rise to 2.5. With a stock solution at an EC = 4.0 dS/m only once a stock solution has to be made.
- Adding small quantities of acid to realise the required pH of 5.5 (fine-tuning the pH). This amount must be registered too.
- Registration of data to look back later (next crop).

Step 4: diluting stock solution to create a day storage (Figure 4)

- Diluting the stock solution with neutralised water (EC drops from 4.0 to 1.0).
- The daily quantity of water required will be max 4 L/m^2/d. As there is a loss of 50% we calculate with 8 L/m^2/d. Calculate the required quantity per day for all plants irrigated and check with the propagator if raised there.
- The quantity of stock solution used and the amount of water added are registered.
- The dilution is measured with an EC meter as supplied to the propagator.
- It may be necessary to add a very small amount of acid manually to bring the pH to 5.5.

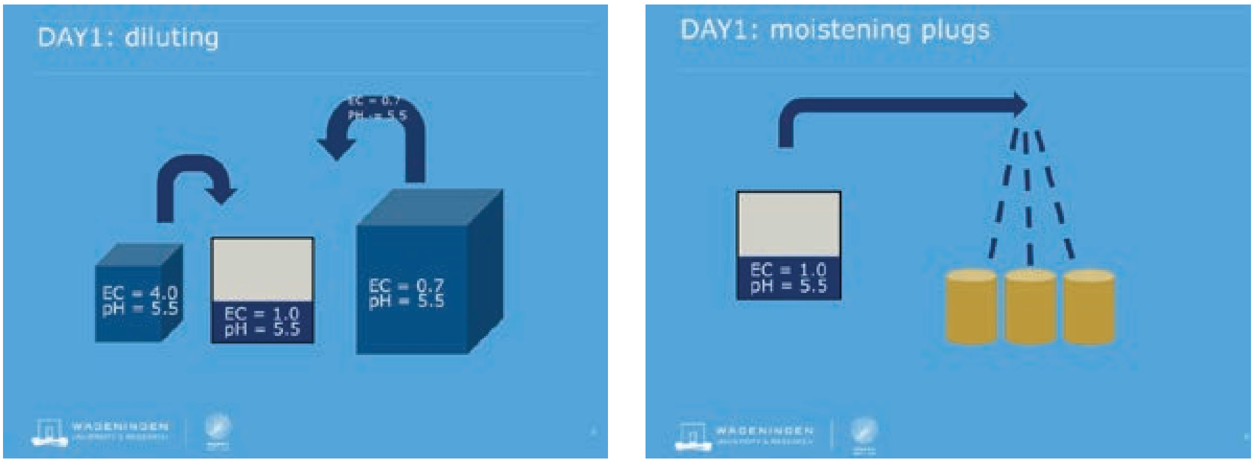


Figure 4 *Step 4 Dilution (left) and Step 5 moistening the plugs (right).*

Step 5: moistening of plugs (Figure 4)

- The diluted stock solution is used to manually irrigate the plugs (overhead).
- Make sure the plugs are soaked thoroughly before seeding!

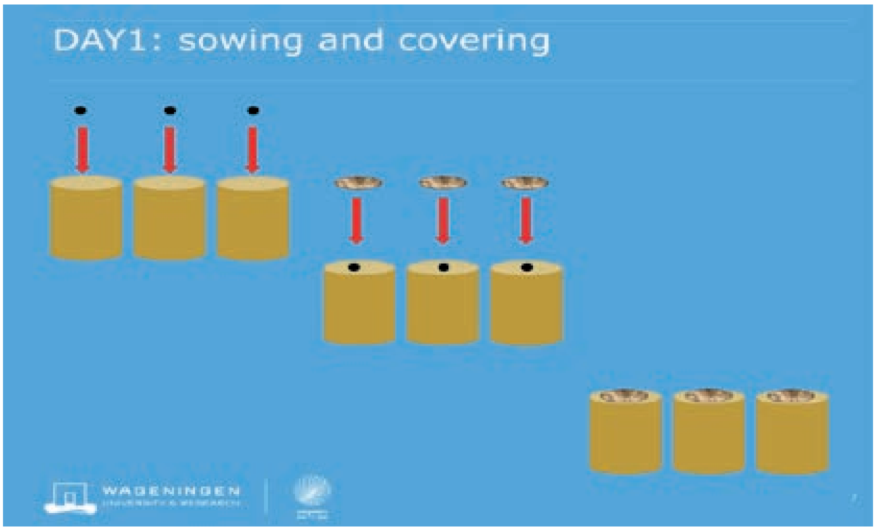


Figure 5 *Step 6 Sowing and covering with vermiculite.*

Step 6: sowing (Figure 5)

- Seeds are manually put on the plugs.
- Vermiculite is added to cover the plugs (do never use peat/perlite as this remains too wet).
- Some nutrient solution may be added to moisten the vermiculite.
- At all times, during the whole propagation, only fertilised water has to be used!

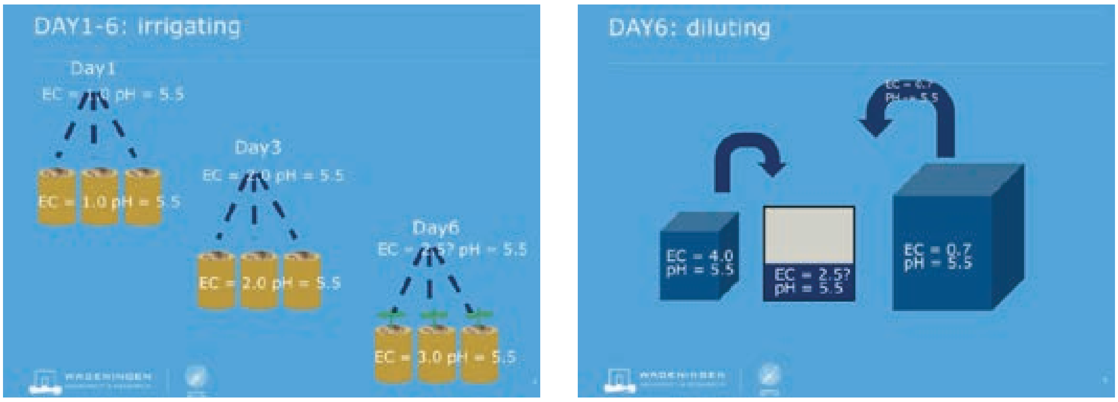


Figure 6 *Step 7 Irrigating with increasing EC (left) and step 8 diluting stock solution to the proper irrigation EC (right).*

Step 7: irrigating day1 to day6 with increasing EC (Figure 6)

- Plugs receive irrigation with fertilised water of the right EC to create an ECplug of 1.0 at day 1 and EC 3.0 at day 6 in the plug. For this the supply EC is increased from EC 1.0 to presumably EC 2.5 in the plugs by changing the irrigation water EC (less dilution from stock solution container). The actual needed EC has to be decided by the propagator or the grower based on experiences after judging the plant and measuring.
- The normal care is taken to avoid burning of the leaves with nutrition; at moderate EC it is enough to irrigate in the early morning and late evening (avoiding direct sunlight).
- When dealing with ECs of the diluted stock of >3.0, a light shower on the leaves with neutralised water might be needed to prevent leaf damage by fertiliser salt.
- This phase will take 8-10 days longer when plants are grafted (see chapter 2.3).

Step 8: new diluted solution with increasing ECsupply (Figure 6)

- Diluting the stock solution with neutralised water.
- The daily quantity of water required will be max 4 L/m²/d. As there is a loss of 50% we calculate with 8 L/m²/d. Calculate the required quantity per day for all plants irrigated and check with the propagator.
- The quantity of stock solution used and the amount of water added are registered.
- The dilution is measured with an EC meter.
- The most important thing is to create an ECplug which is high enough to keep the plants short, dark and increasingly hardened.

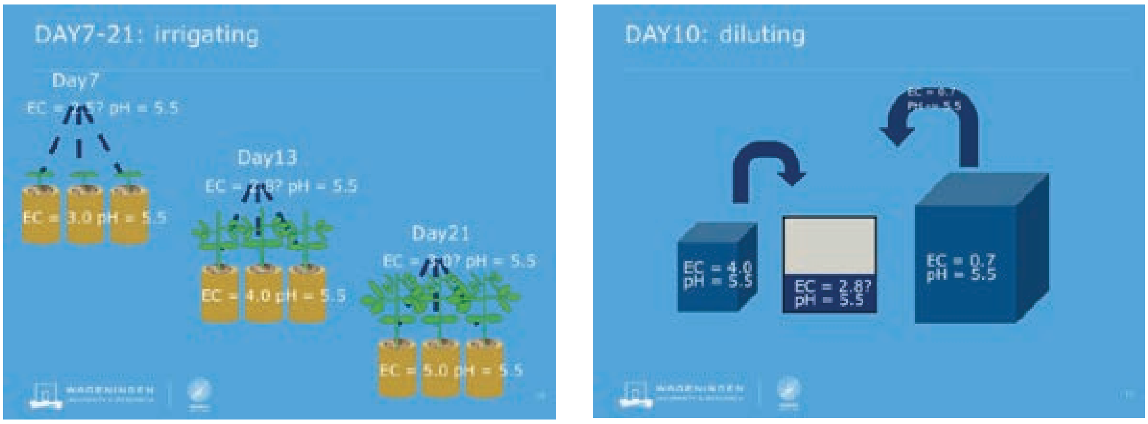


Figure 7 *Step 9, irrigating day7 to day21 and step10 diluting the stock solution.*

Step 9: irrigating day7 to day15 (Figure 7)

- Plugs receive irrigation with fertilised water of the right EC to create an ECplug of 3.0 at day 7 and EC 5.0 at day 15.

Step 10: diluting the stock solution with neutralised water (Figure 7)

- The daily quantity of water required will be max 4 L/m^2/d. As there is a loss of 50% we calculate with 8 L/m^2/d. Calculate the required quantity per day for all plants irrigated and check with the propagator.
- The quantity of stock solution used and the amount of water added are registered.
- The dilution is measured with an EC meter.
- The most important thing is to create an EC plug which is high enough to keep the plants short, dark and increasingly hardened.

Transport and transplanting into blocks or slabs

If transport takes place from the propagator to the grower with the plants in plugs to be planted in slabs, the propagation ends here. This is also the case if the grower raises his own plants and will plant directly into the slabs. Plants in plugs should be transported upright, not compressing on each other. Trays may be stacked in crates or multilevel trolleys or any system ensuring there is enough distance to allow plants to be upright. Directly on arrival plants are transplanted into the slabs. No waiting time is acceptable as plants will stretch to undue lengths much more rapidly than the traditional plants. Before planting in the slabs the slabs should have been thoroughly wetted at least one day before with a nutrient solution of EC 2.5 which should be 1.5 -2.0 EC point lower than the EC in the plugs. The lower EC of the slabs stimulates the growth of roots from the plug into the block. The slabs should have been predrilled to have holes of such a diameter to easily hold the plugs and a depth of the hole of maximum half the height of the plug. Plugs must protrude above the slabs to keep the stem and top root dry enough to avoid disease risks.

If the propagator or the grower spaces the plants from plug into blocks, according Table 1, the plants stand one week at 100 plants/m^2 and there after one week at 16 plants/m^2. For irrigation the steps 9 and 10 can be repeated by creating an ECblock of 5.0 dS/cm.

2.3 Grafting

Grafting is done to stimulate the growth or to bring in tolerance/resistance against root diseases. A description follows below, in Figure 8 an picture overview is given. Grafting is only advisable if there is info that the grafted varieties are a proper combination in terms of yield, quality (Blossom End Rot, BER) or disease advantage. The grafting itself weakens and slows the seedlings and offers a possible entry to viruses and diseases via the wound. If the grafting procedures are not strict and the staff very well trained, grafting can be counterproductive. It is very important that the diameter of the stem of graft and rootstock are the same. There is only one day when this is optimal and grafting must be done on that day. Furthermore it is not very likely that different varieties from the same sowing date can be grafted at the same day as stem diameters will likely differ.

Logistics

- Sowing scion and root stock on the same day (variety dependent).
- After 13 days plants are grafted with only 1 or 2 days in the right stage.
- Grafting when sitting at a table.

Material

- Grafting clips of 1.6 – 1.8 mm are used, if they are too wide the graft will not be tight enough, with room between root stock and scion.
- Disposable razor knives are used to cut. the double edged ones can be broken down the middle.
- Trays will be planted as a chequer board: One hole open, one planted etc..
- Hand held plant spraying equipment with water.
- Alcohol to disinfect the knives every half tray.

Handling

- Cut the root stock (decapitation) per half tray, working from the middle to the front.
- (Right) hand with the razor, behind the root stock, keep razor horizontal and then cut down under angle of 45 degrees. The plane of the cut then should be parallel to the length axis of the tray.
- Cut under the seed lobes and leave about 1.5 cm.
- After cutting spray the plantlets with water.
- Put on the graft clips, with the opening (and hence the handle of the clip pointing in the other direction) perpendicular to the plane of the cut i.e. opening to the right as seen from the operator.
- Push the clip until half of the clip length is on the root stock.
- If necessary hold the plant with the other hand and keep the razor in hand when possible (putting down is allowed).
- Cut the scion above the seed lobes.
- (Right) hand with the razor, behind the scion, keep razor horizontal and then cut down under angle of 45 degrees. The plane of the cut then should be parallel to the length axis of the tray.
- Put the scion in the clip on the rootstock making sure the angle of the scion's cut fits exactly on the angle of the root stock's cut.
- Shove down the scion until the cuts touch.
- Moisten the plants by spraying water.
- Turn the trays and do the same as above with the other half of the trays.

Follow up

- Put the moist trays under plastic.
- Ca 1 week, remove the plastic slowly, giving the plant time to adapt.

NB This is a Dutch approach and intelligent modifications might be necessary in Jordan. A very crucial feature is to make sure the scion and root stock do touch tightly over the whole plane of the cut.

Figure 8 *Overview of the grafting process.*

3 Substrate systems

There is not one perfect growing system. One can make use of slabs, containers or bags filled with substrates as stonewool, coir, sawdust, perlite or another local substrate. In the chapter below an overview is given.

3.1 Soil preparation

Changing from soil-bound to soilless cultivation still means that soil preparation has to take place to minimize the outbreak of diseases and additional growth of weeds. Often the soil is filled with soil-borne pathogens which decrease yield and or quality of the produce. Measures to be taken before start:

- Disinfection of the soil in the traditional way: seeds in the upper layer are destroyed by steaming or a chemical method. When neglected certain weeds may germinate and grow in the greenhouse being a host for pest and diseases. Clean the environment around all the tunnels too. No weeds, pests and diseases should get a chance to survive. These spots are all starting points for new infections lowering your yield.
- Keep the soil dry: no seeds can germinate.
- Level the soil on a slope of 0.5% - 1% in the length of the greenhouse: troughs can be laid down on the soil and will use the natural gravity to drain. At the lowest point the drain collection pipe is dug into the soil. Alternatively the soil can be levelled side ways to guide the drain to a foil trough (Figure 9, right);
- Cover the soil with a plastic liner (Figure 9). There are two alternatives:
  - White liner: it reflects the incoming light giving better light conditions for the plant, especially interesting in spring/summer cycles. Better is even a black/white liner, white at the top, black at the bottom against weeds.
  - Black liner: taking up heat during day time and releasing it during the night. This liner can be the proper choice in winter crop which can use the additional heating.

  If in an unheated tunnel the night temperatures may drop below 12°C, a black liner may be recommended as it will increase the amount of heat stored in the soil and increase a little bit night time temperatures. If the greenhouse is heated and light in dark winter days is the limiting factor a white liner might be a solution. Both liners protect against germination of weeds. The liner must be 0.1 mm thick to have a good strength and to avoid cracks and causing accidents. The liner can be made of a closed film or a woven anti-rooting liner. The latter is preferred if frequently water comes on the liner, it can seep through the plastic, fallen at a closed film it gets slippery and algae will grow.

Figure 9 *Covering the soil with a closed white liner before planting (left), an anti-rooting liner (middle; surplus water leaches away), closed liner on a sideways sloped soil (right).*

After laying down the throughs, the substrate will be placed. Know at forehand the space between the slabs. The drippers are placed and water with fertilizers is used (see start schedule in Table 9, 10) to fill up the slabs. If coir is used, it has to be clear if the coir is buffered with Ca and if the Na is flushed away or not. If not, buffering has to take place with $CaNO_3$. Flushing with water is of no use. So filling the coir boards have to be done with a $CaNO_3$ solution with an EC of 2.0-2.5 mS/cm. After filling, leave it 24 hours or more, here after you can start flushing with a start solution (Table 9 or 10). Now the coir is ready to plant.

- Now planting can take place. Care should be taken for a lower EC in the slab compared with the block. After planting drain holes are made with a thin stick to let the surplus water smoothly flow away without overflowing the troughs and soil in the greenhouse. After a few days the entire front of the slab at the lowest point can be opened by a knife. If a block with a 6 weeks old plant is used, the plants have to be bound to the string immediately.

3.2 Planting fruit vegetables in a row structure

The layout of the greenhouse is dedicated by the crop to be planted. Most crops have a row structure. Between the rows the distance is fixed, within the row the plant distance is more flexible. The row distance is firstly dedicated by the greenhouse structure and the distance of the stands or the width of a single tunnel. In Venlo type greenhouses the most used distance is a multiple of 0.8m. In the past stands were at 3.2 m with 4 rows at 0.8 m. Later the width was increased to 6.4 m and now 8.0 m is mostly used between two stands (a bay or span). Multi plastic tunnels often follow similar distances. In Spain parral type greenhouses often have row distances of 2 m, a very wide path followed by 2 rows in 40-60 cm. This is done to have a good microclimate within the rows, which should not be reached if all rows are uniformly distributed over the space.
In the past, tomato, sweet pepper and aubergine were grown in 4 rows per 3.2 m, so at 0.8 m row distance, plants grew straight upward to the wire. By introducing soilless culture, with investments in substrate and troughs, a so-called V system is used. Rows (with substrate slabs) are at 1.6 m, while each other plant is trained to the left or to the right creating 4 rows with the head of the plant at 0.8 m. Consequently, plant distance within the row was halved. Later developments are to count the number of stems per plant and to work with the number of stems per m^2. It makes the costs of plant material to be bought lower. Tomato grows with 3 – 6 stems per m^2, having 2 plants per m^2. In spring, when there comes more light, a side shoot is maintained, once or twice, to catch the extra light. In autumn one of the stems is removed again. Often those extra stems get a different string colour. Sweet pepper is mostly grown with 2 or 3 stems per m^2.
Cucumber and melons were always grown, because of their vigorousness, in rows at 1.6 m.

How much volume of substrate is needed? 11 litre/m^2
Often a slab volume is 12 L (133x12x7.5 cm). Slabs are also available in lengths of 100 and 200 cm, while width varies from 10 to 15 cm and height from 5-10 cm. It is recommended to have about 11 L/m^2 substrate. Less substrate is more risky because there is less water buffer in the substrate. The required litres of substrates in the greenhouse has to be calculated based on the configuration, eg. if you choose for 2 or 4 rows per 3.2 m or 2 or 3 plants per slab or 10, 12 or 15 cm wide slabs. If there is more than 11 L you can think of making some space between the slabs within the row or placing an extra plant on a slab (from 2 to 3 plants per slab). If you calculate 9 L/m^2, you increase the width or the height of the slabs.

For each planting and slab system, first decide the number of plants per m^2 and then calculate the amount of litres substrate per m^2, as both will influence yield and safety.

3.3 Tomato, aubergine, sweet pepper

Tomato, aubergine and sweet pepper are crops with a rather long growing period, mostly 2 cultures per year if there is no climate control. Usually 2 plants with 3-6 stems per m^2 growing in rows at a distance of 1.6 m. The low number of rows make it possible to lay down a substrate more economical (investment is much lower compared to covering the entire greenhouse area).
The substrate used is mostly a fixed slab (stone wool, polyurethane foam) or a loose one in bags (peat, coir, perlite; Figure 5 and 6). Substrate cultivation started with peat (80s), but it was soon replaced by stone wool (80s up to now) and later also coir (from early this century) came into the market. Peat appeared to stay too wet and rewetting after drying was difficult, reason to change to easier substrates. Stone wool, mostly represented by Grodan or Cultilène, developed into perfect substrates with many different product varieties for specific conditions. Irrigation, drain and water content are optimised by the producer. Slabs in different sizes are delivered enveloped in water tight plastic, which makes uniform wetting very easily with drip irrigation. A big disadvantage is the transport costs caused by its volume and the limited number of factories available.

Coir reduces the transport volume by drying and pressing the slabs into boards which take up water very easily. Further it can be delivered in various grades, changing the water content characteristics of the material according requirements of crop and grower. It is delivered in the enveloping liner, which makes wetting easy. Perlite and polyurethane foam are substrates of which the pore volume can hardly be influenced during manufacturing, as a consequence there are less grades, products, available for the crops. Perlite has often a low water capacity, PU foam is more expensive; both have a long life span. The choice of the substrate is often based on the ease of working during the entire cultivation period and of course the marketing of the manufacturers.

Figure 10 *Left: two plants in a bag with one in-line dripper does not give plants a good start: uneven irrigation delays immediate growth. Middle: a slab in a rigid polyester trough which can be suspended. Right: roots growing all through the slab, drippers on the block, a good situation.*

Figure 11 *Left: tomatoes in a granulated substrate in bags.* 2^{nd} *from left: stone wool slabs on metal troughs to avoid hanging stems touching the ground.* 3^{rd} *left: elevated bags to promote drain. Right: if bags are not firmly standing water content in the bag is not uniform creating a different and mostly a less growth.*

Per 1.6 m row there is one drip line with In-line nozzles (Figure 10, left) or drippers with spaghetti tubes (French cappilaries) or pressure compensated nozzles (preferred, but a little more expensive). As water capacity of the substrate and the volume is small, frequent irrigation is required. Troughs (Figure 11) can be made simply from plastic liner but are sensitive for leakages. Polypropylene, polyester or coated steel have a much longer life span but investment is higher. In conclusion: more frequent irrigation usually means a higher yield, reason to choose low release drippers. Pressure compensation avoids supply differences caused by >5 cm height differences and by irrigation time differences between drip line beginning and end.

3.4 Cucumber, melon, beans

These crops are a little more sensitive to wet conditions. This is reason to avoid the use of “wet” substrates (high water contents) such as peat and to choose for drier substrates as perlite or stone wool and coir. Otherwise the system is similar: 2-4 plants per m^2, growing in rows at mostly 1.6 m distance, realizing a plant distance within the row of 0.3 – 0.7 m. For irrigation see 6.1.

Figure 12 *Cucumber plant just placed upon the stone wool slab. The supporting stick has been stabbed into the slab to avoid falling (left). Courgette planted in buckets will be spaced soon (middle). Perlite, depending the grading is a suitable substrate for cucumber (right).*

3.5 Lettuce: butterhead, baby leaf, iceberg; herbs

Different types of lettuce are nearly always planted in NFT (nutrient film technique) or DFT (deep flow technique) systems. Explanation: final plant density is usually more than 20 plants per m^2 which require a full coverage of the soil with substrate and would become very expensive. Besides it is a crop with a short growing cycle realising 4-8 crop cycles a year, depending on the harvest weight (150 – 500 g). It is uneconomic to replace the substrate after each crop cycle. The consequences would be that 4-8 crop cycles lead to accumulation of substrate by the plant raising pot and thus another substrate volume with other physical and chemical characteristics because of root remnants and fertilization. Consequently, the irrigation and fertilization strategy has to be constantly adapted.

Cultivation in water systems as NFT and DFT is much simpler: the entire plant, including roots, is taken out the troughs. Lettuce heads are brought to the market, the roost and substrate block composted and the troughs are cleaned.
NFT: A common and cheap systems is made from PVC pipes provided with holes (Figure 13). Placing on a slope of 0.5 – 1.0% on racks is sufficient; maximum length of 20 m; width of 10 cm. Disadvantage is the round bottom (little aeration, wetting the substrate too much resulting in increased risks on fungal diseases), reason to use square profiles with a flat bottom (Figure 13). Most systems have fixed distances between the troughs. Very sophisticated systems make use of movable troughs which stand close to each other at the beginning and are spaced during the cultivation to a final distance between 15-25 cm. At the bottom of the troughs there is always a thin layer of nutrient solution which circulates continuously. If not, there is no buffer and plants will dry out soon. Systems can be simple but also fully mechanized (Figure 14).

Figure 13 *NFT lettuce in round pipes (left and middle); square pipes (right) are preferred for the flat bottom and more uniform conditions.*

DFT: beds or boxes of 0.5 -2.0 m are used and filled with 10-20 cm layer of nutrient solution. Length also varies very much: 0.6 m – 20 m (Figure 14). DFT has a large buffer capacity and plants will never dry out. However, there is a risk of lack of oxygen around the roots. A certain circulation has to take place. In DFT the system needs to be filled with a different nutrient solution at the start (start solution) than the solution to be added during the cultivation (if replenished at all). The reason is the need to start with higher calcium and magnesium levels and no ammonium at all. Otherwise the K/Ca ratio will be off and leaf edges will die back.

Figure 14 *Left: plants raised in peat blocks in special trays for planting in NFT system. Fully mechanized lettuce production where troughs are automatically spaced and transported to the harvesters (Hortiplan, middle and right).*

Figure 15 *Left: the NGS plastic liner with iron frame system (not movable) gives also good production. Middle and right; DFT from Dry Hydroponics with 60x40 cm panels floating on the nutrient solution.*

Another possibility is a multilayer system at which troughs are placed above each other. Practically a grower has to deal with uneven growth of different layers because of different amount of light intercepted and temperature. The result is a much lower annual yield as might be expected from the increased number of plants per m^2. This can be somewhat optimised by the use of artificial light or change to a closed building ad cultivation in a vertical farming unit. Both methods demand high investments which are not discussed here.

3.6 Strawberry

In soil, with soil-borne pathogens, the utilization of space is poor. In substrates, at which the plants stand in containers or troughs at racks, fruits are hanging in the air and less vulnerable for diseases as Botrytis (Figure 16) and the utilization of space is increased. Cultivation shifts from outside to simple tunnels towards advanced greenhouses at which the full control of required temperatures to obtain flowers and fruits made it possible to grow strawberries during a much longer season. Finally a production of more than 10 kg/m^2 per year is possible now with mostly good prices during the entire season. There is a rapid change from soil to soilless growing realizing more production with a good quality.

Figure 16 *Left, middle: outside grown strawberries in containers with coir. A liner against rain can be drawn over the plants. Right: strawberries are touching the plastic causing quality loss; ridges or a higher substrate may avoid touching.*

Figure 17 *Left: in bags; middle: in open containers with coir; right: in NFT with a polypropylene cover with plant holes.*

The substrate system is mainly based on peat or coir (Figure 16, 17). However stone wool is also possible but it is more difficult to plant a young plant that usually has already a large root volume. Round containers (20 cm diameter) filled with peat or coir are placed on scaffolds, often about 3 plants per container, and irrigated by drip irrigation. Extremely important is the start of the cultivation (Figure 18), directly after planting the roots have to penetrate the new substrate which must be sufficiently wet and having a lower EC if plants are raised in pots. Small irrigation turns with high frequency are important here to keep the substrate uniformly wet. Scaffolds and containers are placed at a height of 0.8 – 1.2 m (according to requirements). Often open systems are used without recirculation. However much water and fertilizer can be saved by recirculating the nutrient solution. It is preferable to collect drain water anyway, to keep the soil beneath the plants dry, avoiding weeds and pests to grow there.
Sometimes a NFT system is used (Figure 16, 17) on which plants in small pots (10 cm), filled with coir are placed directly in the trough with a thin water layer. There is a big risk with this system for a too wet substrate causing various root diseases.

Figure 18 *Left and 2nd left: an example to avoid: too broad slabs where fruits are unable to hang on both sides of the slab, while number of irrigation points is unequal to number of plants resulting in dying of plants (irregular growth). 2nd right; suspended metal troughs with coir filled containers. Right: PVC round pipe with 15 cm containers. Again we advise to make the plugs stick out of the slab as they become too wet when fully inserted.*

4 Climate Control

4.1 Introduction

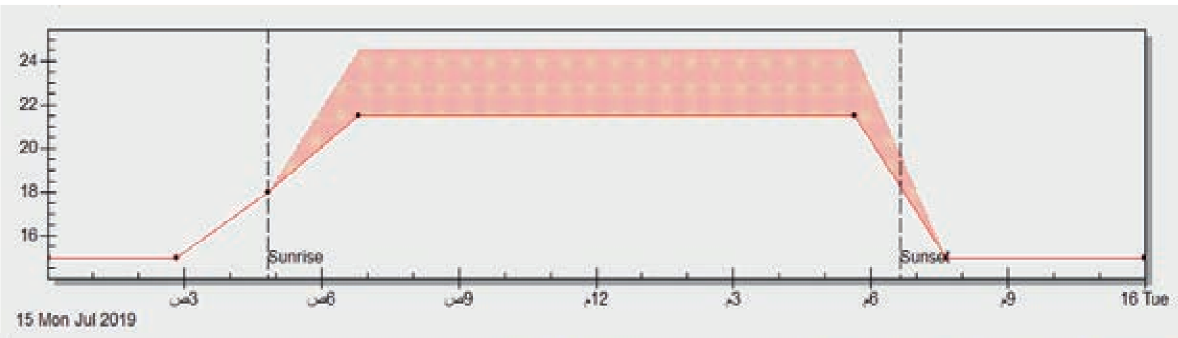
In this chapter we focus on the most important indications on how to make the right set points for the climate control in a mid-tech greenhouse in Jordan conditions. We will focus on 2 important aspects: meteorological set points and management of natural ventilation, screen and a fog system.

4.2 Meteorological set points

Storm set point: this is the wind velocity at which windows get to storm position to prevent damage of the greenhouse and the structure. For Jordan 12 m/s is a good value. Then, you need to set up minimum and a maximum storm position. The minimum must be zero. Our recommendation is to set a maximum opening at storm at zero for the windward vents and at 10-20% for the leeward vents, but always check visually if this maximum position is not damaging the greenhouse. The windows start closing before the storm set point is reached, so do not be surprised if windows start closing.

4.3 Ventilation control

It is important to understand that temperature and radiation are intimately linked. If there is plenty of radiation available, then the optimum value for photosynthesis switches to a higher value, and vice versa. Therefore, the ventilation set points must include also an influence for radiation. As we can see in Figure 19, as radiation grows from 600 W/m^2 to 1000 W/m^2 (see Table in Figure 19), the ventilation set point rises gradually to a maximum of 3 degrees (red shading in graph). So at more light a higher temperature in the greenhouse is allowed. This, of course, is an example, and values can be fine-tuned to each greenhouse and location, by establishing some values and observing the resulting climate. In Winter period, a similar influence can be added, this time for humidity. In this way, if internal greenhouse humidity is above a certain value, we can decrease the ventilation set point temperature and vice versa. Spring and Autumn are intermediate periods at which manual change of setpoints might be needed.



	Period state			On	On	On
	Start time			-02:00	00:00	-01:00
	Relative to			Sunrise	Sunrise	Sunset
Baseline average	Change			02:00	02:00	02:00
18.7	Value		24.3	18.0	21.5	15.0
Influence (!)	From	To	Now (!)	1	2	3
radiation: measurement - W/m^2	600	1000	2.8	0.0	3.0	0.0
No influence						

Figure 19 *If more radiation, from 600 to 1000 W/m^2, ventilation starts at a 3°C higher temperature.*

The set points for windward vents are usually set 1 or 2 degrees above the set points established for the leeward vents, because with leeward vents climate is more homogeneous and windward vents must only open when they are really needed for example as the leeward vents cannot maintain the set point.
Minimum vent position: it can be set both for windward and leeward. Normally it is set to zero in heated greenhouses, but in unheated greenhouses it can be set to a higher value, to help controlling humidity values.
Wind and leeward side vent position humidity: this can be used also to open the windows if humidity becomes too high. In Figure 20 a measured RH deviates from the RH set point, vents will open gradually. If deviation is higher than 20%, vents will open completely.

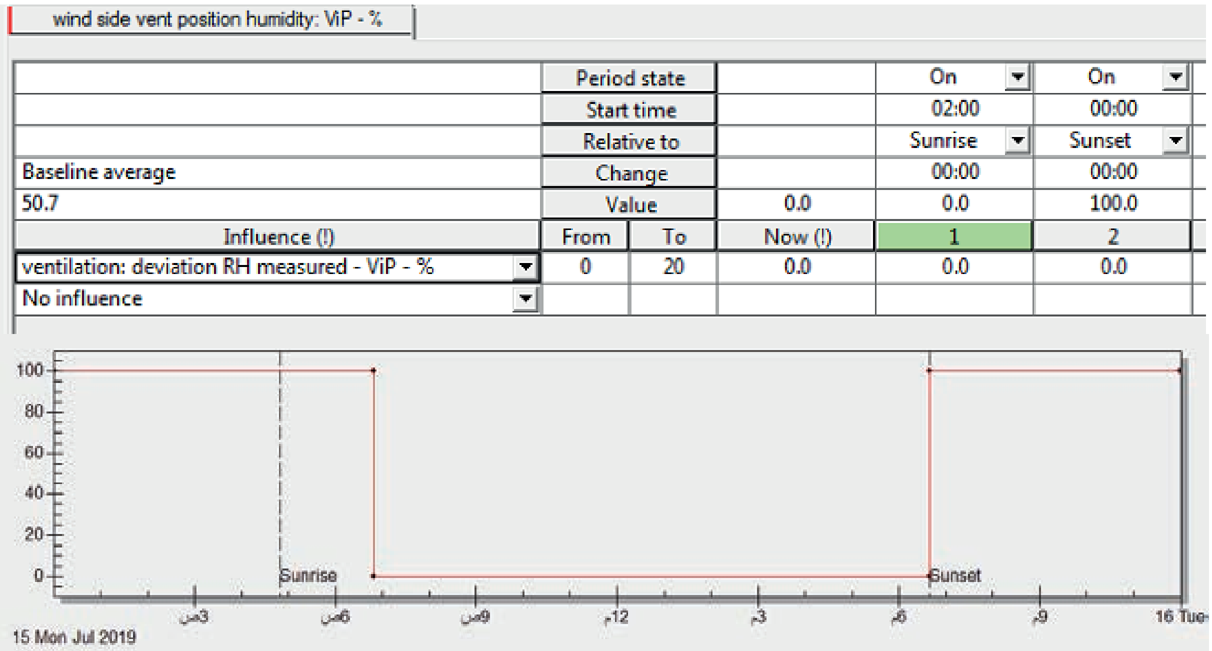


Figure 20 *If RH measured is 0-20% higher than the setpoint, the windows will gradually open. More than 20% difference will open the windows completely.*

4.4 Screen control

If the screen is used as a shading screen, we must establish a radiation set point above which the screen will close. Sometimes, although radiation is high, temperature may not be very high, and then shading is not really needed. In order to close the screen only when both radiation and temperature are high, we can add an influence as the one we can see in Figure 21. In this case, the screen only opens when radiation is above 1050 W/m^2, which is a rather large value that will not be reached. However, if temperature is between 30 and 32°C, this set point is lowered gradually to a maximum of -300 W/m^2, which means that if temperature is 32°C or higher, set point becomes 750 W/m^2.
If the screen is used as a thermal screen, the set point is simple. You only have to establish the outside temperature and radiation value below which, the curtain will close. In Jordan, for tomato and sweet pepper, value of 15°C and 20 W/m^2 are good. Also, if radiation becomes higher than 40 W/m^2, it will open. More sophisticated use of the thermal screen would be the use of a screen gap, dead zone and the stepwise opening and closing of the screen. It will not be discussed here.

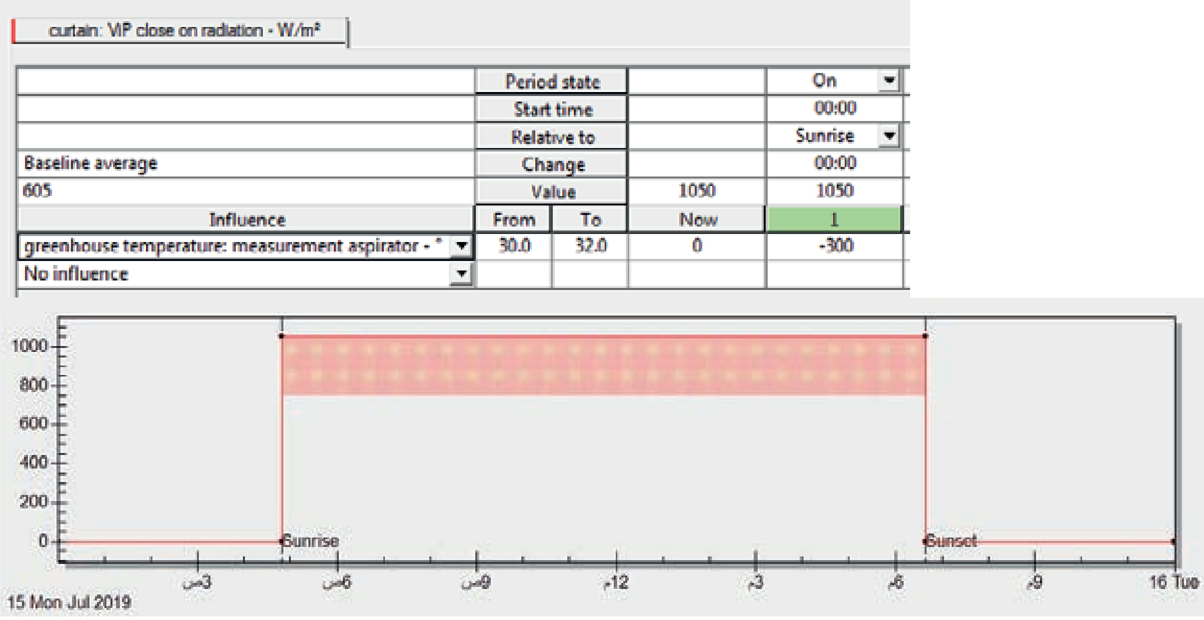


Figure 21 *Shading at high radiation and high temperature.*

4.5 Fogging

The main settings for a fog system are: the duration of the pulse and the duration of the interval that there is no fogging, even if the set point is not reached (Figure 22). This is done to prevent that the systems runs continuously and wets the crop.

Settings	Unit	Value
humidification: type of control		misting
pulse length: ViP	m:s	00:00
interval pulse: ViP	m:s	01:00

Figure 22 *Pulse length and interval for fogging.*

The pulse length is established with an influence. The influence is the difference between the desired RH set point and the measured RH value. When the difference is higher than -10%, then the pulse will be set to the maximum value that has been input, in this case 25 seconds (Figure 23). As the RH. approaches the set point, the pulse will gradually become shorter, and when RH is reached, the pulse value becomes zero.

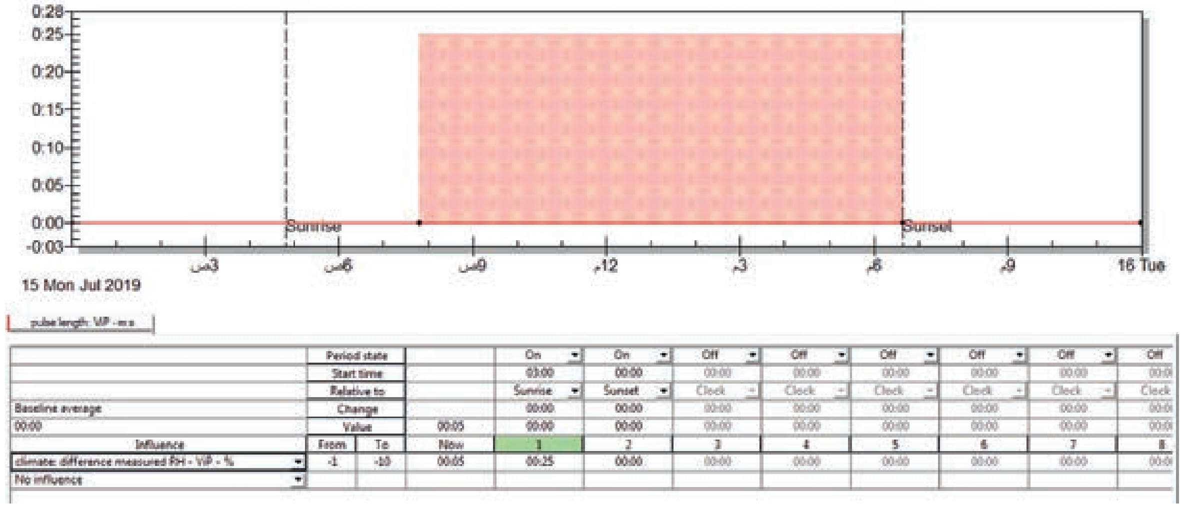


Figure 23 *Pulse length influenced by RH.*

For the interval, the same thing is done (Figure 24). In this case, as we are closer to the set point, the interval becomes larger (up to 1 minute long when difference between measured RH and set point is larger than 10%) and as we are further away, it becomes lower being the minimum interval 10 seconds.

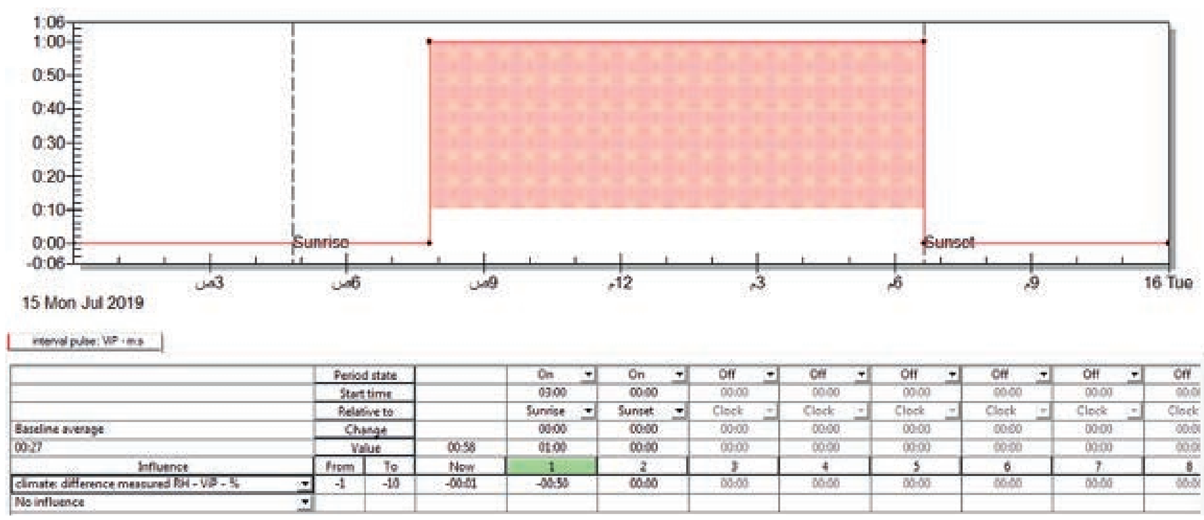


Figure 24 *Pulse interval influenced by RH.*

4.6 Temperature set-points

The diurnal average temperature and, to a lesser extent, the profile of the temperature over the 24 hours period is a major factor that affects the growth of a tomato plant. In Table 2 a short overview is given for several stages.

Table 2
General overview of temperature set-points for tomato.

Stage	Minimum	Maximum	Average
Germination	18	24*	21
Vegetative growth	16	30	21
Fruit setting	16	30	21
Ripening	14	30	21

*) 28°C when seed is still covered.

4.7 General remark

When a certain condition is reached an action is started. E.g. when the temperature reaches 26°C the windows start to open. But they will not open immediately to the largest opening possible. E.g. they will have fully opened only at 32°C. As you can see the action starts at 26°C with 0% opening and ends at 32°C with 100% opening. This applies for all regulations. The system is called a P-band regulation. All P-band regulations have a start and end value and react proportionally from minimum to maximum values between the start and end value. It is of importance to understand that regulations can be too fast (start and end values too close) and too slow (start and end values too far apart). Especially in Jordan with extreme values and large variations between night and day, these P-bands need to be discussed continuously and possibly adapted to the circumstances.

5 Cultivation

5.1 Tomato

Tomato (Solanum lycopersicum) is a flowering plant of the nightshade family (Solanaceae), cultivated extensively for its edible fruits. Labelled as a vegetable for nutritional purposes, tomatoes are a good source of vitamin C and the phytochemical lycopene. The fruits are commonly eaten raw in salads, served as a cooked vegetable, used as an ingredient of various prepared dishes, and pickled. Additionally, a large percentage of the world's tomato crop is used for processing; products include canned tomatoes, tomato pastes, tomato juice and ketchup. However, these processed tomatoes are of a low quality grade and are generally grown in the open field, not in greenhouses.
Contrary to growing tomato in the open field (horizontally in a bush), greenhouse tomatoes are grown vertically as single stems winded in a string. This means that side shoots that constantly emerge from the top-part of the plant are removed (about weekly). Depending on the cropping season, cultivar used, in the initial growing phase one shoot, or sometimes even two or three shoots, may be kept to increase stem density. This is only applicable when planted in the season with increasing light. In case of the season with decreasing daylength, the number of stems has to be reduced by topping and removing the additional side shoots (6 weeks before removal date). Also in case a stem gets damaged or dies, a neighboring stem can be used to generate an additional stem to replace the broken one. However, it will be clear that the root-system of a plant gives limitations to the number of stems supported by these roots. Two to three stems per root system is no problem, but when going to higher number of stems per root system, the root-capacity will become limiting. In case of a planned long term crop and deliberately additional stems, grafting is therefore recommended.
The single-stem approach means that the stems will become very long, up till 15 meter, in case of an 11 months cropping season. For such long crops, prefarably the high wire system is applied, using hooks with wrapped string, that supports the plant, which can be elongated by rolling out the hook which it is attached to the supporting training wires (Figure 25).

Figure 25 *Stems are wound in a white or red string wound around hooks which hang on the wire.*

In principle, a tomato plant is grown 10 to 11 months after which it is replaced by a new cultivation cycle. Theoretically a plant could grow even longer, but since the nutrient- and water supply becomes more and more challenging as the stems become longer, this 10 to 11 months growing period is a kind of practical timespan. Also, during the growing cycle, more and more plants will drop-out due to diseases or mechanical damage. Alternatively two cultivations per year may take place. The turning point is mostly a cold, humid winter causing plants to die or a hot summer avoiding setting of fruits. It has to be realized that the annual production of two cultivations is always lower than one cultivation a year for tomato and also for sweet pepper because of the long starting period without yield. The latter is not valid for cucumbers. In Jordan the hot season will be the turning point. So a start in August and ending in June/July if one crop may pass the winter period. If not, two crops are planted and an additional change takes place in December/January.

5.1.1 General planning of the cultivation

Globally activities in a tomato crop can be scheduled according Table 3. Note that week 1 might be in August or in January depending earlier choices.

Table 3

General planning of a tomato crop.

Time	Activity	
Week 1	Sowing and raising transplants	See chapter 2.2
Week 3	Transplanting	See chapter 2.2
Week 7	Placement in the greenhouse	The plants should be approximately 25 cm tall at planting on the slab. Temperature greenhouse 20-21°C.
Week 8 - 16	Vegetative growth	Plants grow to the wire, are frequently twisted into the string (once a week), flowers are pollinated (bumble bees, self-pollinator or by hand) and set fruits grow to ripe tomatoes.
Week 17 - 45	Harvesting period	Harvesting starts around week 17 and can be continued till it gets too cold or too hot or too many plants are dying because of diseases.
During cultivation	Crop maintenance	From planting onwards side shoots (1-4 cm long) have to be removed weekly and main stem has to be twisted into the string. After the first harvest leaves has to be picked to get more light on the ripening fruits, always pick leaves up to the ripening truss, not higher, about 3 leaves per week. Prune the trusses to 5-8 fruits (depending the radiation) for round tomatoes (50-70g) to get a uniform ripening and size. Six weeks before ending the crop the head of the plant is removed to give it a chance to put all energy into the ripening of the last fruits.
	Drain water samples.	Every two weeks water samples of supply and drainwater should be sent to the lab to analyse its nutrients composition to determine what components need to be added additionally and what components should be reduced in the A and B tank in the fertigation unit. Preferably each 2 weeks the A and B tank are refilled. Twice a week water samples from drainwater, slabs and supply are taken and measured with the hand EC/pH meter. Data are written down in a logbook to see developments.
	Scouting for diseases and insects	Working personnel should scout the plants constantly while working in the crop. They should report if they see insects, fungi or other uncommon symptoms.
Week 43-45	Irrigation stopping	Stop 1-3 weeks before end with irrigation to empty the slabs to make removal easier.
Week 46	Remove crop and clean greenhouse	Remove the old crop and the substrate and clean the greenhouse to prevent pests and diseases.

5.1.2 Crop management

Vegetative and generative

The term 'plant balance' describes where plants put their energy in. It can be described in various ways: as the balance between leaves and fruit, or between vegetative and generative plant parts, or between 'source' and 'sink'. It all has to do with sugar production (energy), leaves at one hand and fruit (energy consumption) at the other, per unit of area. 'Source' refers to the amount of assimilates (sugars) that are produced in the leaves due to photosynthesis. 'Sink' refers to absorption of those assimilates in growing organs, such as fruit, plant head, young leaves and roots. The terms 'vegetative' and 'generative' can only be used for crops that produce flowers and/or fruit. If in a certain period, a plant puts most of its energy into leaves, and not much into fruit, we call this plant vegetative. At another point in time, the same plant can be heavily loaded with fruit, while leaf growth is limited. The plant is then called generative. Too vegetative or too generative are not desirable states, because the plant is not in balance and the long-term production will suffer. A number of plant characteristics can be assessed to determine at an early stage if a plant tends toward vegetative or generative growth. If detected early enough, the grower can take action before the plants get out of balance. Stress factors, like a high temperature, big difference between day and night temperature, low humidity, less fruit pruning, more removing of leaves, high EC-level or a limited water supply are considered to push a tomato-crop to the generative side. Opposite actions will push a crop to a vegetative growth. The results over the whole season are better if the plants stay balanced throughout the entire season. Table 4 shows the factors and the control actions that can be used to steer plants in vegetative of generative direction (Nederhoff & Houter, 2007).

Table 4
Factors and control actions to steer growth.

Plant balance	**Plants are too vegetative** (head strong and leafy, top of plant heavy, growing fast, not enough flowers)	**Plants are too generative** (head small, plant top meagre, growing very slow, many new flowers, possibly many fruit)
Possible causes		
Genetics	Vegetative variety	Generative variety
Grafting	Grafted on strong root-stock	Not grafted on strong root-stock
Plant stage	Young	Mature
Season	Autumn, winter, spring	Summer
Growing system, medium, irrigation *	Ample water availability, or wet growing media (eg NFT)	Poor water availibility, e.g. dry growing media
Plant management *	*	*
Growing conditions	Favourable, mild	Harsh, excessive (e.g. radiation)
Greenhouse	Lower/softer radiation, higher humidity (e.g. double plastic)	Higher/sharper radiation, slightly lower humidity (e.g. glass)
Energy screen, shade screen	Increasing humidity, lower radiation under shade screen	No screen used
Stress	Little or no stress	Stress from heat or dryness

Possible control	**To steer in generative direction**	**To steer in vegetative direction**
Radiation	Allow higher radiation	Shade to avoid excessive radiation
Temperature	Give higher day temperature (watch the 24 h temperature)	Reduce day temperature (if needed increase night temp)
Pipe temperature	Give higher pipe temperature (with venting if needed)	Lower the pipe temperature
Air humidity	Give lower (harsher) air humidity	Give higher (milder) air humidity (by screening, adjusted venting, fogging, misting, roof sprinklers)
CO2	Increase the CO2 level	Lower the CO2 level
EC or CF *	Give higher EC (or CF)	Give lower EC (or CF)
Water in root-zone *	Drier root-zone	Wetter root-zone

** To be dealt with in future articles.*

Elly Nederhoff & Bert Houter, April 2007

In Table 5 steering measures are given for the irrigation to steer vegetatively or generatively.

Table 5
Steering vegetative or generatively with irrigation set-points

	Unit	Generative	Vegetative
EC supply water	mS/cm	Higher	Lower
EC around roots	mS/cm	Higher	Lower
Water content of slab		Decrease	Increase
Drip frequency	Times/h/d	Less	More
Length of drip turn	Min/time	Longer	Shorter
First irrigation	Time	Later	Earlier
Last irrigation	Time	Earlier	Later

Stem density
One of the first plant management decisions is about plant density, or better stem density. Stem density has a direct effect on plant balance. Normally tomatoes are grown on one or two stems. The stem width is controlled through factors like temperature, carbon dioxide, light and EC-level. If the new formed stem becomes too thick (more than 10 – 12 mm), the following factors may be increased: temperature, carbon dioxide, shading and water stress.

Pruning (fruits and shoots)
Pruning is the removal of all lateral growth (side shoots) that appears in the leaf axillary, and the best time to remove them is in the first stage of growth (1-4 cm length), because removing of large side shoots causes yield loss (loss of assimilates) and makes big injuries to plant stems which increases the risk of fungal infections. Bottom leaves and leaves in contact with the soil are also removed to reduce the spread of diseases and to obtain good ventilation to prevent development of fungi. Moreover, bottom leaves eventually receive insufficient light and rather use more energy than they contribute to the net-assimilation. Fruit thinning or cluster pruning can be used to control the fruit load on the plant, and to adjust the ratio of ‘sink’ to ‘source’ in various seasons. Depending on the tomato type or variety and the season (light intensity), clusters should be pruned to 4 fruits (tomatoes of about 200 g) to 12-14 fruits per cluster (cherry tomatoes of about 12 g).

Cutting leaves
Tomato plants always make three leaves for every cluster, generally 12 to 15 leaves per plant are sufficient to have the optimum light interception, in summer and winter usually remove at about 3 leaves per week since every week a cluster is developed. Leaves are best cut with a sharp knife in the afternoon because then it will be too hot to do work in the top of the crop.

Lowering (high wire system)
In a greenhouse the plants are attached to a string. When plants reach the horizontal wire, the plant need to be lowered. The timing depends on the speed of growth, but is mostly done every week. It is best to leave about 20-30 cm between the plant and the wire. Lowering of the crop can best be done in the morning because then it is not too hot high in the greenhouse. Harvest and cutting leaves is preferably done before lowering. The lowering process should be done very carefully to avoid breaking the stems or loosing fruits from the clusters. In case stems still break, the plant might survive when stem is taped with plastic tape to support the stem till the injury coalescence.

Winding / Clipping
Winding or clipping is important to support plants to grow vertically in or along the string. It must be taken into consideration and follow the right winding way in one direction and achieve enough winds around the stems to avoid damaged leaves and stems. Winding has to be done every week. Delayed winding process may cause breaking of the stem and dying of the plant. Instead of winding, which is a generative action, plastic clips can be used for fixing stems to the ropes. The use of plastic clips is being preferred at high radiation and temperatures, because it causes less stress to the plant.

Pollination
Tomato flowers are in principle self-fertile. However, the probability of self-pollination for the varieties that are used in greenhouses is very low (<10%). Greenhouse tomato varieties therefore are only capable of reaching their high productivity when the pollination is carefully supported, either by manual pollination ('Ticking' of the plants) or by making use of bumblebees.
Under greenhouse conditions bumblebees (*Bombus terrestris*) or local Bumbus species reach a 100% success rate. This is much more than what is achieved by manual pollination or by using hormones, where average pollination ratios of 70% are the benchmark Figures. Moreover, the quality of the fruit set is better when bumblebees are used for pollination. Fruits become more spherical and smooth.
The bees pollinate flowers by transferring pollen that got stuck on dense and small hairs on the bee's body and by shaking of the flowers and truss when the bees land and take off from the flower.
Finally, having bumblebees to do the pollination work saves (management of) labor.
A box with bumble bees stays active for 6 to 8 weeks, at temperatures range of 8-32°C and with the availability of pollen. The boxes are placed from beginning of flowering stage. A small box suites about 400 to 500 m^2. The boxes are placed away from direct sunlight and in a cool place. It pays off to cool the boxes as bumble bees will stop pollination to start to cool the hive by creating air flow in the hive with their wings; if this is not necessary they will stay pollinating at somewhat higher temperatures.
To confirm the pollination process by the bumble bees, the color of the stigma can be checked. After pollination the color changes from yellow to partly brown. This feature is not available in other pollination methods. Boxes have to be replaced by new ones if one sees that the bees are becoming less present in the greenhouse and when brown-coloring of stigma in flowers cannot be seen.

Guidelines should be followed to avoid effect of pesticides on bees. There are three situations:
- Pesticides permanently banned because of their deadly effect on bumblebees.
- Pesticides that require removing of the hives from the greenhouse. Before end of the day, leave the entrance open to bees and close the slot exit, next day make sure all of bees entered the hives. Then remove the hives before spraying pesticide.
- Pesticides that can be applied with hives inside greenhouse. In that case cover cells during spraying and re-open them after completion.

5.1.3 Harvest

Harvesting is done based on indicators ripeness, coloration and size of the fruits. Harvest records will show the production. Sometimes a grower wants to experiment with various cultivation aspects. In this way you can distinguish if more than one cultivar has planted or training of the plants is different or more or less fruits per truss is maintained. To get reliable data a plot has to exists of at least 10 plants. Further at least one, but preferably 2 or 3 replicated plots are recommended. First and last plant are clearly marked and one person of the staff should be made responsible for the harvest and data collection of these plots.

5.2 Sweet pepper

Below (Table 6) a description is given for the production of sweet pepper for daily fresh delivery. One planting period a year is sufficient for year-round production. The production of pepper is difficult since it is very sensitive on nutrient and climate factors. The production needs a good grower in combination with a cultivation advice.

Table 6

General information for a sweet pepper crop.

Crop	Sweet pepper
Varieties	There are numerous varieties in sweet pepper suitable for greenhouse production from different seed companies (Rijk Zwaan, Enza etc.). Categories are block, long and hot. Block peppers are most common in Europe. Green peppers are favoured on the Chinese market. Care for varieties coming from a renowned breeding company, realizing a seed package with the required resistancies and purity, but also for the good season weather (Jordan Highlands or Jordan Valley).
Seed	Most seeds are resistant to various diseases and can be bought from the seed companies. Look to what you need in your situation.
Sowing time	The sowing time in soilless culture is similar to soil. The best period for sowing should be based on the market. However, in a climate controlled greenhouse production can also be realised during periods others growers are not on the market, realizing a higher price. If market prices are low, this might be a good period to change the crop.
Sowing places	Nursery (greenhouse) with temperature, humidity and light regulation.
Nursery temperature	The temperature in the nursery is between 20 and 26°C.
Transplanting dates	Summer seems best from the market point of view. Sweet pepper is planted once a year.
Plant density	A planting density of 3 plants/m^2 is recommended. During growing 2 stems per plant are grown (6 stems/m^2). It is also possible to have a plant density of 2 plants/m^2 with 3 stems per plant. More stems per plant is recommended for high light conditions such as in Jordan, compared to a Dutch winter.
Temperature control	With the goal of directing growth and maintaining optimum plant balance for sustained high yield production, the 24-hour mean temperature can be manipulated to direct the plant to be more generative in growth, or more vegetative in growth. Optimum photosynthesis occurs between 21 to 22°C. Optimum temperatures for vegetative growth for greenhouse peppers is between 21 to 23°C, with the optimum temperature for yield about 21°C Fruit set, however, is determined by the 24-hour mean temperature and the difference in day - night temperatures, with the optimum night temperature for flowering and fruit setting at 16 to 18°C.
Root zone temperature	Root zone temperatures are primarily managed to remain in a narrow range to ensure proper root functioning. Target temperatures for the root zone are 18 to 21°C.
Relative humidity	The relative humidity should not exceed 90% for longer periods (more than 2 hours). A relative humidity less than 50% should also be avoided for longer periods.
Carbon dioxide	Optimal CO_2 concentrations for the greenhouse atmosphere fall with the range of between 700 to 900 ppm (parts per million) during day time. The best advice for CO_2 supplementation under high ventilation rates is to maintain the CO_2 concentration at or just above the normal ambient level of approximately 350 ppm. This is a highly efficient way of using CO_2 supplementation. Maintaining the CO_2 concentration at the same level as ambient, there can be no net exchange of CO_2 with the outside air through leakage or ventilation.
After harvest treatment	The products should be kept between 15 and 25°C after harvesting.

6 Plant nutrition and irrigation

First a description of the required water quality and irrigation strategies (6.1) which is followed by the functions of the individual main (6.2) and trace (6.3) elements, including the effects of deficiencies and excess. Hereafter, the nutrient solution and the preparation of a recipe is described (6.4) including the target values around the roots.

6.1 Water quality and Irrigation strategies

Water quality
The plants need water to grow, to transpire to cool themselves, to transport nutrients to leaves and fruits. Various sources of water might be available. For example in The Netherlands rainwater is obliged to be used for it is a good quality and is mostly sufficiently present. In Jordan one has to think of surface water from the canal, bore hole water of reclaimed waste water.
Generally speaking the volume supplied to the plants in a greenhouse with a soilless system with recirculation is 6-8 l/m^2/day for a full grown crop. Maximum transpiration per hour is about 7-9 l/m^2.
The amount you need is also depending the quality of the water. There are a number of aspects:

- Total salt of the water:
  - EC >1.5 dS/m; not suitable for horticultural culture.
  - EC 1.0 – 1.5 dS/m; use in soil grown crops.
  - EC 0.5 – 1.0 dS/m; open systems without recirculation (drain percentage >20%).
  - EC<0.5 dS/m; closed or recirculation systems.
- Effect of salinity: If the EC is too high, the yield decreases if the EC rises with 1 mS/cm:
  - Cucumber: 8.8%.
  - Lettuce: 4.6%.
  - Sweet pepper: 12.6%.
  - Tomato: 6.5%.
- Sodium and chloride: important if the EC is below 1.0 mS/cm and soilless culture is chosen. There are more or less salt tolerant crops, see decrease in yield above, but more specific it can be said that sodium (Na) plays the most important role:
  - Na or Cl >1 mmol/l; only open systems.
  - Na or Cl 0.5 – 1.0 mmol/l; open systems and closed systems with a high sodium uptake such as tomato
  - Na or Cl <0,5 mmol/; nearly all crops can be grown in a closed system.
- Bicarbonate (HCO_3) makes the water hard and increase pH to 7 or 8, mostly combined with high Ca or Mg levels:
  - HCO_3 > 8 mmol/l; unsuitable, only correction possible with nitric acid (HNO_3) or phosphoric acid (H_2PO_4).
  - HCO_3 > 0.75 mmol/l; neutralisation with Ca and Mg fertilizers is possible.
  - HCO_3 < 0.25 mmol/l; good.
- pH: preferably between 5.5 and 6.0. Mostly higher if there is HCO_3 with Ca or Mg. P-uptake of decreases if pH>6.
- Iron (Fe): if total iron > 100μmol/l; find alternative water source; >50 μmol/l de-ironing to 10 μmol/l when drip irrigation is used. Iron easily blocks the drippers.

Irrigation Frequency
In Table 5 an overview is given of several irrigation strategies and reasons one should change from the original strategy. Generally, the yield increases with increasing frequency, so give the smallest possible quantity with the highest possible frequency (at least more than 10x per day, having drippers of 2 L/h). First, choose the smallest release of drippers (2 l/h) and realise more than 10 irrigations per day of 2 minutes each, depending on the solar radiation. Start 1-2h after sunrise and stop 1-2 h before sunset. During the night there is no irrigation. You can limit the irrigation frequency by varying the drain percentage (15-30% of the supply).

Drain

Due to genetic differences between plants, place in the greenhouse and variations in the release of the drippers a surplus of water has to be supplied to the plants to give them all enough. The surplus is related to the supply and is called the drain percentage. The drain percentage should be 15-30%. When below 15% (EC around roots will increase) increase the irrigation frequency, when above 30% decrease the frequency; both by decreasing/ increasing the interval between two irrigations.

Interval

Plants should be irrigated according to the radiation sum (2-3 ml/J/cm^2) they receive and when they are small also according to their light interception. Once the area of the leaves of the plants have 3 times the floor area (plants in a high wire system reach the horizontal wire; LAI>3) they transpire at maximum level. A full grown crop will have a more or less constant LAI of 3, because of the regular pruning of leaves and the growth of new leaves at the top of the plant .

6.2 Main elements

All main elements have a specific function in the plant (Table 7). Consequently symptoms may appear if too much or too little uptake takes place. Besides the uptake can be disturbed because of the presence of other ions. In soil symptoms are less dominant, but in soilless culture with less root volume and buffer, symptoms may appear within days, which in many cases cannot be solved within days. Therefor it is important to know the details.

Table 7

Uptake, interference, deficiency and excess symptoms of main elements.

Nutrient and function	Uptake interference	Deficiency symptoms	Excess symptoms
Nitrogen – N Amino acids, DNA, chlorophyll, hormones	denitrification	Growth reduction, low vigour, yellowing of older leaves	--
Phosphorus – P DNA, ATP/ADP for energy	Poor root system reduces uptake potential. High Ca, Fe or Al concentration in soil (high or low pH resp.)	Growth reduction, stunted growth, purple discolouration of older leaves, dark green plant tops	Seldom, induction Fe, Zn deficiency
Potassium – K protein synthesis, water balance, membrane polarity	Competing with other cations (Mg, Ca or NH4), fixation of K in clay minerals	Yellowing of margins and tips of older leaves, progressing to whitebrownish spots and then ‘scorching’ (necrosis) of leaf margins, growth reduction	Ca or Mg deficiency possible, may reduce sugar and starch in root crops
Calcium - Ca Membrane synthesis, stabilization, role in root pressure	Other cations (K, Mg), inhibition of transpiration (high humidity, dry soil, heat)	Pre-mature dropping of buds and blossoms, bending of tips, blossom end rot in tomato, necrosis of extreme parts	Induced Fe deficiency, also B, Mn, Zn; competes with Mg uptake
Magnesium – Mg In chlorophyll	Especially Ca	Interveinal chlorosis/yellowing, mottling, green veins, orange, red or purple discolouration possible, leaves may curl at margins	Ca or Mn deficiency possible
Sulphur – S proteins		Similar to N deficiency, light green to yellowish leaves with lighter coloured veins	--

6.3 Trace elements

Table 8

Uptake, interference, deficiency and excess symptoms.

Nutrient and function	Uptake interference	Deficiency symptoms	Excess symptoms
Boron – B Cell division, carbohydrate transport	High pH inhibition of Transpiration (high humidity, dry soil, heat)	Deformation of tissue (leaves, root tips, fruits	Leaf necrosis in old leaves, leaf senescence
Copper – Cu Specific enzymes for generative development	High pH	Various symptoms, pale to yellowing of leaves, flower degeneration, bud abortion	In roots
Iron – Fe Chemical reactions, electron transfer, enzymes	High pH (>7), high Ca level,	Interveinal chlorosis, leaves become whitish, veins remain green, in top of plants	Chelate toxicity
Manganese – Mn enzymes	High pH	Chlorosis, different from Fe: grey yellow, finer green veins, youngest leaves still green	Bark substrates may contain excess Mn, spotting or necrosis along leaf margins, leaves roll up
Molybdenum – Mo Nitrogen fixation	Low pH	Legumes show N-deficiency symptoms, upward curling of leaves, deformed leaves	Unknown
Zinc – Zn Specific enzymes	High pH	Interveinal chlorosis, stunted, bleached appearance, yellowing of complete plant, necrotic spots, leaf deformation	Chlorosis, Fe and Mn deficiency

6.4 Nutrient solution of tomato, sweet pepper

Nutrient solutions are based on extensive research in the past 30 years (Sonneveld & Voogt, 2009; De Kreij *et al.* 1999). From the nutrient solution, as given in Table 9 for tomato and in Table 10 for sweet pepper a recipe can be calculated, which prescribes the quantity of fertilizers one have to add, which is usually prepared as a concentrated stock solution; the A and B tank. The basic nutrient solution is crop specific and applicable anywhere, however the translation into a recipe may locally differ depending on the available fertilizers.

Table 9

Standard nutrient solution for tomato.

Element	Closed system	Open system	Target value in root environment
EC, dS/m	1.6	2.6	3.7
pH			5.5
NH_4, mmol/l	1.0	1.2	0.1
K	6.5	9.5	5
Na			<8
Ca	2.75	5.4	10
Mg	1.0	2.4	4.5
NO_3	10.76	16.0	23
Cl			<12
SO_4	1.5	4.4	6.83
HCO_3			<1
$H2PO_4$	1.25	1.5	1.0
Fe, µmol/l	15	15	25
Mn	10	10	7
Zn	4	5	7
B	20	30	50
Cu	0.75	0.75	0.7
Mo	0.5	0.5	0.5

Table 10

Standard nutrient solution for sweet pepper.

Element	Closed system	Open system	Target value in root environment
EC, dS/m	1.6	2.6	2.7
pH			5.8 - 6.2
NH_4, mmol/l	0.5	0.5	0.1
K	5.75	6.75	5
Na			<8
Ca	3.5	6.0	8.5
Mg	1.125	1.5	3
NO_3	12.5	15.5	17
Cl			<12
SO_4	1.0	1.75	3
HCO_3			<1
$H2PO_4$	1.0	1.25	1.2
Fe, µmol/l	15	15	15
Mn	10	10	5
Zn	4	5	7
B	25	30	80
Cu	0.75	0.75	0.7
Mo	0.5	0.5	0.5

A tool to calculate the recipe (from mmol/l to kg fertilizer) was made by Incrocci (2015) and can be downloaded from the Internet: https://www.wur.nl/en/Research-Results/Projects-and-programmes/Euphoros/Calculation-tools/Nutrient-Solution-Calculator.htm.

6.4.1 Preparing a new recipe

To prepare a new nutrient solution this step wise approach can be followed:
- Start with the required nutrient solution, this can be found in the nutrient solution manual (De Kreij *et al.* 1999) or use Table 9 or 10.
- Fill in the correct nutrient solution in the calculation tool (Incrocci, 2015).
- Choose or fill in the available fertilisers with proper specifications in the calculation tool.
- Use the calculation tool to make a recipe for the proper A and B tank size (i.e. 250 L) and the proper A and B dilution ratio (i.e. 100x).
- Double check (compare with previous calculations and ask a second opinion).
- Prepare the fertilizers and fill the tanks.
- Register what is made.

When fertilisers are going to be used from an unknown or untrustworthy source, consider first having these tested. Dissolve a known quantity, like 2 g/l in element free (distilled or demineralised) water and send a sample to a lab for a complete range of elements to be tested. The analysis will tell you if the claims on the bag are right and what types of undesired ions are present and in what concentration.

6.4.2 Taking drain and supply control samples for laboratory analysis

Additional to twice a week sampling of the supply and drainwater with the EC/pH handmeter, samples have to be taken to analysis the nutrient composition by a laboratory. The Dutch laboratories can deliver the results within a few days after arrival. Make sure that the chosen laboratory can deliver the analytical result in a few days too and not after weeks. Procedure:

- Take a sample from the drain water and one from the drippers at multiple places to make sure the sample is representative.
- Fill the bottle to the rim and close the cap.
- Add a label on the bottle with unique code/grower/date/crop/type of sample (raw water/irrigation solution, drain solution, etc).
- Keep a registration form with the same information as on the bottle.
- Measure the samples with one's own EC/pH handmeter and register.
- Make sure the EC of the raw water is between 0-2 mS/cm and for nutrient samples between 1-8 mS/cm. If not, notify the lab.
- Store the samples immediately in a dark and cooled environment (T<10˚C and preferably T<5°C).
- Ship the samples to a lab as soon as possible.

6.4.3 Analysing and adjustment of the composition of the nutrient solution

Preferably each 2 weeks an analysis should be made of the nutrient solution. Adjust the moment of sampling such that after receiving the analysis from the laboratory the A and B tank are nearly empty. Those analysis can be judged by the Incrocci calculation tool and will result in a new A and B tank recipe.
Alternatively there is a stepwise manual approach:

- Start with the list with recommended values of the nutrient solution for the root environment (target values; Table 9 or 10).
- Then convert the analysis results to match them with the EC of the recommended root solution i.e. multiply each result with the ratio $EC_{recommended}/EC_{analysis}$).
- Compare EC and pH analysis with target values.
- Compare the converted nutrient data with the target values for each individual ion. Now compare the converted analysis for elements on cation/anion sum, K/Ca ratio and check the EC against the cation and anion charges present.
- If the deviations are too large, very generally > 10-20%, change the supplied recipe to compensate the surplus or lack of the element considered. Please ask advice or a lab to decide when to change as this is highly element dependent.
- The changes in the recipe for the supplied solution can be found in tables giving the required change for different deviations above or below the required level. If the tables suggest a change for an element, note the amount.
- Look up the original used recipe for the added solution.
- Correct the added solution by subtracting the amounts found. If the grower needs to give a higher or lower EC then the recipe uses for the added solution, the corrections must be changed according to the ratio $EC_{adapted}/EC_{recipe}$.
- Adaptations to the growing stage should also be added now (see Ch 6.3.4).

6.4.4 Adaptations to the growing stage

There are a few moments during the entire growing season the nutrient solution must be adjusted. Tomato and sweet pepper slightly differ. In Table 11 an overview is given. Start is the filling of the slabs, before planting. Fruit set is during the setting of the first trusses while there is no harvest. High water is only needed when the water consumption per day exceeds the 5 L/m^2 (or mm). End of season is the moment for tomato that the head is taken out of the plant to ripen the last trusses.

Table 11

Adjustments of the nutrient solution for Tomato and Sweet pepper.
Adjustments are compared with Table 9 (tomato) or Table 10 (sweet pepper).

	Tomato				Sweet pepper			
Element	Start	Fruit set	High water	End season	Start	Fruit set	High water	End season
EC, dS/m								
pH								
NH_4, mmol/l	-1			-1	-0.5			-1
K	-1	+1.5	-1		-1	+1	-1	
Na								
Ca	+0.5	-0.5	+0.5		+0.5		+0.5	
Mg	+0.5	-0.25			0.25			
NO_3						+1		
Cl								
SO_4								
HCO_3								
$H2PO_4$				-1				-1
Fe, µmol/l	+10				+10			
Mn								
Zn								
B	+10				+10			
Cu								
Mo								

6.4.5 Fertigation

A fertigation unit mixes fresh water with stock solutions (100x concentrated) from A and B tanks and if needed acid (tank C), as prepared in Ch 6.3.3 and 6.3.4, controls EC and pH and pumps it to the drip irrigation. A general basis recommended EC is listed in Table 9 and 10, for actual situations, these parameters should be tuned to the local situation. Set-points for EC and pH for the nutrient solution to be supplied (drip irrigation) must be chosen and set for the fertigation unit. The recommended EC and pH depends largely on several conditions, like the cropping stage, season and climate. The set-point must be adjusted to achieve the EC target value around the roots (see Table 9 and 10) as a basis. With increasing transpiration (due to increasing radiation) the EC must be reduced to achieve the same values, due to differences in water and nutrient uptake. It should be noted that the nutrient uptake by the plant is affected also by the plant stage. This will have an effect on the required EC of the irrigation, to keep the EC in the root environment at the target level. Further you can change EC to achieve a better vegetative or generative growth (Tables 4 and 5). Explanation about fertilizers is given in Annex 1.

6.4.6 Monitoring

Regular monitoring of irrigation, nutrient supply, nutrient use, development of the crop in relation to EC and pH is demanded for an optimal result. A good and intensive monitoring helps to recognize problems in an early stage and to act accordingly. Monitoring will help to learn more about the crop in relation to the environment and daily conditions, leading to an increased experience of the grower. For EC and pH you have the set-point values in the fertigation computer. Additionally a hand-made control is done twice a week of the EC and pH of the supply water (coming from the drippers) and the drainwater. Once a week a measurement should be taken from the slab.

6.5 Nutrient disorders of tomato fruit

Several disorders may appear on the fruits during the growth of tomatoes caused by various reasons. An overview of frequent appearing symptoms is given below.

Russetting

Figure 26 *Russetting symptoms.*

Symptoms: very small cracks in the fruit skin, bad colouring, grey / dull appearance, short shelf life because of porous skin.
Cause: rigid fruit skin can't absorb swelling of the growing tomato. Mostly occurs 3 - 4 weeks before harvest. Growth stagnation after long dark period, low temperatures, high RH, sudden climate changes;
Prevention: choose for less sensitive varieties, avoid very low temperatures, avoid individual fruits become too big by increasing the stem density, more fruits per truss, higher EC level.

Big cracks (when still on plant)

Figure 27 *Big cracks.*

Symptoms: open cracks in fruit skin over entire fruit.
Cause: Especially caused at irregular fruit setting, during dark weather after a long period with much light. Also common when irrigating with a too low EC or a suddenly lower EC e.g. after a too long start time i.e. too late in the day.

Prevention: choose for less sensitive varieties, prevent irregular fruit setting, care for good flower quality and good pollination by bumble bees, increase EC or decrease irrigation (irrigate on radiation instead of time), prevent shocks in EC, stimulate transpiration: decrease of root pressure (stop irrigation earlier at the end of the day), harvest more frequently: less coloured fruit; immediately after harvest: be aware of low temperature or high RH causing new cracks on harvested fruits.

Discolouring

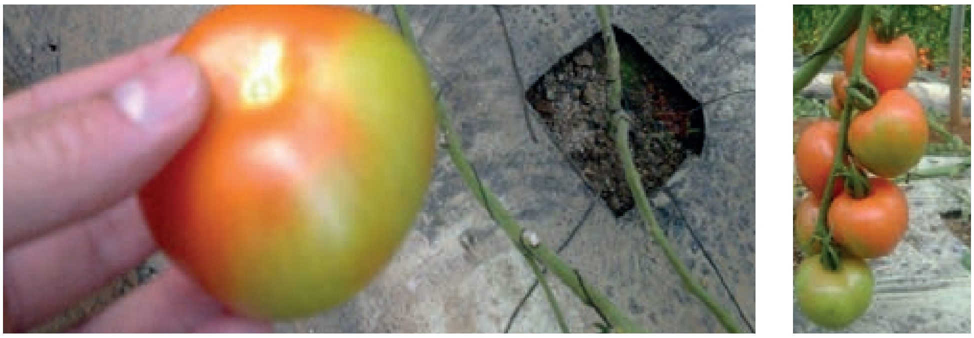


Figure 28 *Discolouring of fruits.*

Symptoms: non-uniform colouring.
Cause: high fruit temperatures (direct sunlight), low nutrition level (EC) and/or very easy uptake of water realizing a strong vegetative growth, low potassium content (lycopene), susceptible variety, virus, Bemisia.
Prevention: good climate and higher EC, regular drain-analysis (indicate low -K), choose for less susceptible varieties, try to prevent virus infection and insects, check and increase potassium level if needed.

Blotchy ripening

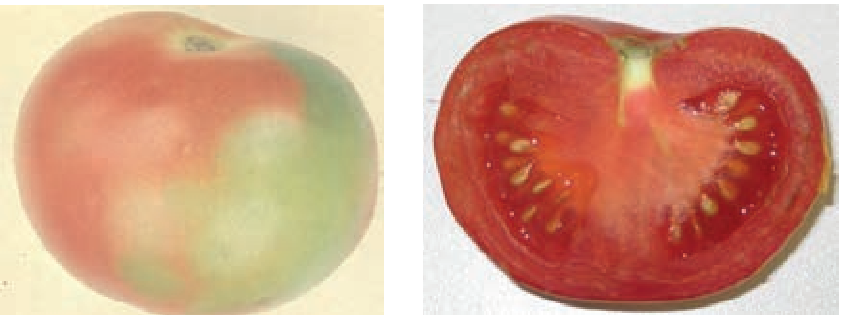


Figure 29 *Blotchy ripening.*

Symptoms: brown vascular bundles and sometimes white fruit tissue.
Cause: Sudden change from long period with dark weather to sunny weather, moisture of tissue is extracted, especially on lower trusses and with very vegetative plants, low K in nutrient solution/substrate and/or EC.
Prevention: Higher nutrition level, especially K, make plant more generative.

Yellowing around calyx

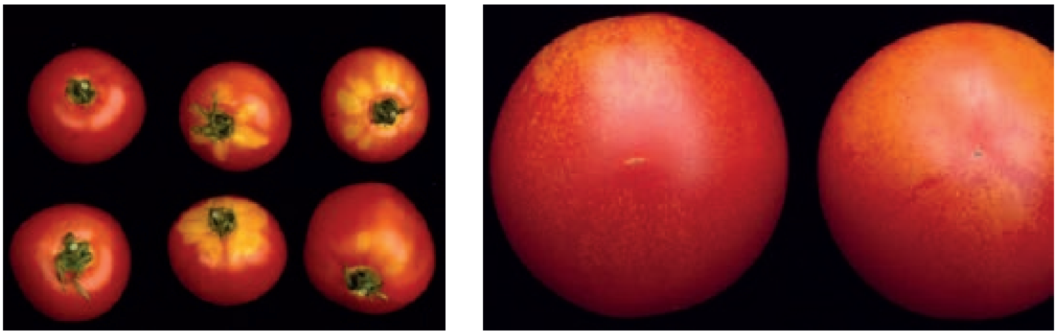


Figure 30 *Yellowing around the calyx (left); Silvering (right).*

Symptoms: around the calyx a yellow collar can be seen, especially in greenback tomatoes.
Cause: high radiation on fruits.
Prevention: choose tomato type without greenbacks, avoid direct sun radiation (cover fruits with leaves), make light diffuse (screens / whitening of crop cover).

Silvering
See Figure 30.

Symptoms: air cavities in tissue directly beneath skin.
Cause: Strong climate changes / high day temperature, often 1st fruits of truss, it is visible in green stage, mostly irregular at time, especially at high EC, no clear effect of variety.
Prevention: good climate control, avoid too high EC.

Blossom end rot

Figure 31 *Blossom end rot.*

Symptoms: brown to black bottom of the fruit, internal black rotting, is susceptible 10 – 20 days after flowering.
Cause:

- Vigorous and rapid growth resulting in sharp decrease in Ca transport to young fruits (Ca is diluted in water flow), it happens especially at imbalance in growth (too vegetative). Two phases: lack of Ca in blossom-end causing weak cells (1), cells burst at situation with stress (‘pressure’/’salt’ (2)).
- Ca plays role in firmness of cell membranes, Ca is less mobile; passive Ca uptake via water flow (temperature dependent), especially uptake by young roots/root tops, passive transport with water flow via phloem to strong evaporating plant parts: leaves!
- >85% of water in fruit is transported via phloem, <3% of absorbed Ca comes in fruits, danger: shortage of Ca in bottom-end of fruit.

Prevention: Prevent high transpiration due to low humidity and high radiation (screening, fogging) choose less susceptible variety, balance in vegetative en generative growth, drastic leaf pruning, removal of top leaves, stimulate uptake of Ca: easier by low EC and Na, humid soil/substrate, create root pressure during night, look for compromise: otherwise other quality problems.

Gold specks

Figure 32 *Gold specks.*

Symptoms: yellow/gold spots on the fruit.
Cause: Ca-oxalate crystals because of high Ca-content. It results in a shorter shelf life, perhaps due to internal damages. More problems at high P en Cl in nutrition and a high RH.
Prevention: variety (more gold spots at strong growth or strong roots), realize a lower RH and/or a higher temperature. Increase the EC or K/Ca ratio or K/Mg in irrigation water.

Golf balls or grafting disease

Figure 33 *"Golf Balls" with uneven skin surface (left); yellow calyxes (right).*

Symptoms: uneven skin surface, only in combination with grafting.
Cause: exact cause unknown.
Prevention: probably differences between varieties/rootstocks. Perhaps more problems with a very vegetative growth.

Yellow calyxes
See Figure 33.

Symptoms: a kind of ageing, fruit stays too long at the plant. Clear effect of variety.
Cause: aging, irregular harvesting.
Prevention: choose the right variety, harvest frequently, postharvest cooling.

Damage during hanging on the plant

Figure 34 *Hanging damage (left); influence shelf life (right).*

Symptoms: small, crooked damages to the skin.
Cause: rough movements of trusses during crop management.
Prevention: better care for hanging fruits.

Shelf life, how to improve
See Figure 34.

- Choose the right variety.
- Not too high air temperature. At high temperature improved colouring.
- Higher EC: stronger skin, with high Na softer fruit.
- Enough K in nutrient solution (also for good colouring.
- Growing on stone wool vs. growing in soil improves shelf life.
- Plant density (adjust to radiation level).
- Avoid kinked trusses, apply truss pruning, have a good fruit set, don’t remove too much leaves.

7 Plant pest and diseases

7.1 Integrated Pest Management

Restrictive and effective use of chemical plant protection products is a perquisite for both the environment, human health and optimal production and product quality. Spraying because there might be a chance on one or another pest or disease is not efficient. The use of integrated pest management (IPM) is a good approach to an effective use of chemical plant protection products. IPM starts with creating optimal growing conditions, monitoring pest and diseases in the greenhouse and then decide if action is needed (Figure 35). First preventive actions like physical, mechanical or biological options are considered. If these do not exist or are insufficient to control the plague or disease a curative (chemical) alternative is selected

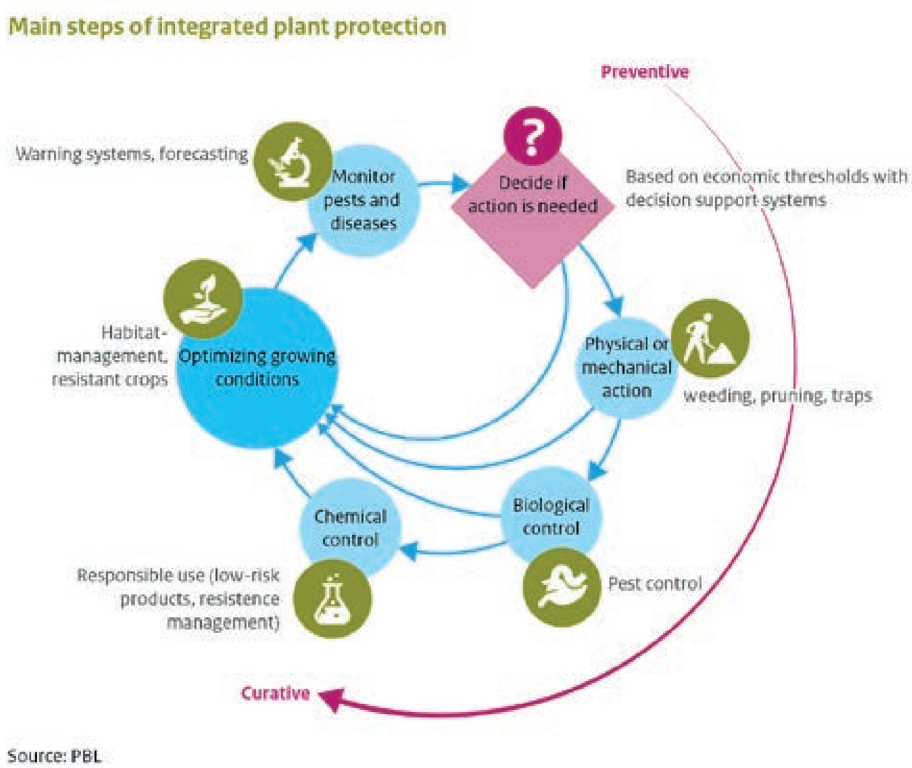


Figure 35 *Schematic overview of IPM.*

7.2 Prevention

Pest free starting material (plants, substrate, soil), use of insect netting and hygiene measures (i.e. Ch. 7.2.1) are important steps to prevent the introduction of pest and diseases to the greenhouse. Optimal conditions for plant growth: like a good climate (Ch. 5), optimal nutrition (Ch. 6) are essential to prevent the development of pest and diseases.

7.2.1 Hygiene protocol for mechanical transmitted viruses

Underneath you find some tips and important information to prevent virus diseases and the transmission of virus through the greenhouse:

1. Transport of virus takes place by:
   - Crop maintenance: taking out suckers, twisting, harvesting.
   - Infected material: knives, shears, clothing, boxes.
   - Remnants of crop: leaves, roots, fruits.
   - Seeds: good quality seeds (as RZ) should be free of virus.

2. Infected plant material:
   - If one plant is infected (clear symptoms) remove it.
   - Remove plants from substrate slab and let dry one day. After one day removal from greenhouse (drier plant, less plant sap, less risk for spreading).
   - Put plants in plastic bag and close.
   - Bring to garbage system, not to compost.

3. During cropping:
   - WORK ALWAYS IN ONE ORDER,
     - In greenhouse: 1st close to entrance on left; all following spans to the end; coming back along the right spans.
     - In path: start left and move backward, return on right side.
     - Left and right can be changed now, but maintain during entire cropping period.
     - If workers see infected plants encourage them to report.
   - Symptoms of virus in row:
     - Mark paths where symptom was detected (hang a red A4 paper or tape at begin of path).
     - Each path one knife!. Place knife after use in buckets with disinfectant.
     - Crop maintenance: first healthy rows and plants. Last: infected rows.
     - Plant remnants (leaves) collected in plastic bag.
   - Workers:
     - Lock entrance doors.
     - Greenhouse is only open for staff to work there, they will have special clothing.
     - Use other clothing (coat/overall/shoes) when working in greenhouse, pull it out after work and hang at entrance.
   - Place disinfection container for walking through per path with infected plants.

4. Crop change:
   - Remove all plant parts accurately, including: string, chains.
   - Don’t shred plant material (release of plant sap); don’t let it blow away.
   - Avoid germination of plants from old fruit seeds.
   - Put all plant parts outside in container with cover, remove container within 24h to garbage station.
   - Avoid leaching of water from plants.
   - Take out substrate, plastic foil, drip lines, floor covering.
   - Use high pressure cleaner with hot water and bleach (50ppm) for cleaning paths and posts and troughs for cleaning.
   - Clean greenhouse once more from back to front.
   - Have an empty greenhouse for 3 weeks to let disinfectant work well.
   - Clean driplines with pH 1 and leave it 24h, after rinse with clean water.
   - Clean nozzles and pegs with submerging them in 10% tri-sodium phosphate solution (pH 13; 10 kg/100 L) for 24h.

5. Machinery:
   - Clean machinery in work shed: lorries, boxes, tools with high pressure cleaner and hot water.
   - Use new clothing, destroy old clothing.
   - Wash hands before entering the greenhouse.

6. New start:
   - Everything is clean: check if nothing is forgotten.
   - Fence off clean and dirty parts of greenhouse.
   - Use a new floor cover.
   - Use new substrate or steam sterilize it at 100°C for 15 minutes.
   - Avoid all animals: mice, rats, cats, dogs; in greenhouse.
   - Raise your plants in new substrate, transport them in clean boxes. If coming from plant raiser demand for clean disinfected boxes.
   - If using own boxes for transport of plants: clean before use.
   - Chemicals to be used.
   - No milk: temperatures too high, stinking, does not work long enough.
   - Brinkman: Menno Florades, long treating time needed. Good for buckets with knives which stand the whole night in the liquid.
   - Virkom: shorter treating time required, but admission in other countries unknown.

7. Visitors:
   - Give them special overalls when entering the greenhouse and throw away after use in special containers. Especially people visiting other nurseries, greenhouses.
   - Place a sign on the doors: forbidden to enter, traffic sign printed on A4 in plastic envelop.

7.3 Monitoring Pest and diseases

It is important to check your crop for the occurrence of pest and diseases, at least weekly. Do this by walking through the rows and look for symptoms, damages or traces of insects. Don’t do this while doing other thing, just concentrate on scouting of pests and diseases. If you see something suspicious check both the upper and lower site of the leaves with a magnifying glass. Register the extend of the damage and the location in the greenhouse.

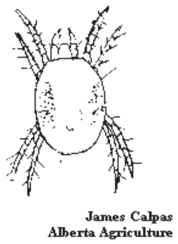
Use sticky traps to get an impression on the presence of the flying insects. Yellow traps work well for white fly, aphids and leaf miners. Blue traps work best for thrips. Change them weekly and register the number of insects.

Ask the staff doing maintenance work or harvesting to report about pests and diseases when they are passing by.

7.3.1 Management of pests and diseases in tomatoes

Table 12

Main pests in tomatoes.

Name	Symptoms	Conditions for development	Specific control measures
The two-spotted spider mite		The two-spotted spider mite (*Tetranychus urticae*) is a common pest of a number of greenhouse crops. Typical symptoms of two-spotted spider mite infestations include speckling of leaves and fine webbing on the underside of affected leaves. As the spider mite population increases, the leaves become brittle and brown in color, the amount of webbing on the leaves becomes very prominent and the mites can be seen milling about on the webs.	Effective biological control of the two-spotted spider mite is obtained by introducing the predatory mite *Phytoseiulus persimilis* as soon as two-spotted spider mites are detected in the crop. *P. persimilis* does well in the pepper canopy, and once established throughout the greenhouse it controls the spider mite population for the remainder of the season. The mites *Amblyseius fallacis* and *Amblyseius callifornicus* are closely related to *P. persimilis* and establish well and gives better control under low density mite situations, but should be used along with *P. persimilis.*
Thrips		There are two species of thrips that are common pests in greenhouse vegetable crops, the western flower thrips (*Franliniella occindentalis*), and the onion thrips (*Thrips tabaci*). Thrips feed by opening wounds on the plant surface and sucking out the contents of the plant cells, the feeding results in small whitish streaks on the leaves and fruit and can cause distortions in the young developing fruit.	There are a number of predators available for biological control of thrips: predatory mites *Amblyseius degenerans, Amblyseius cucumeris, Hypoaspis miles* and *Hypoaspis aculeifer* and predatory bugs, *Orius insidiosis* and other Orius species.
Fungus Gnats		Fungus gnats are commonly found in practically all greenhouse crops. Fungus gnats are an indicator of moist conditions in the greenhouse and populations generally grow to be quite large early in the year or whenever there is pooling of water on the greenhouse floor. Adult fungus gnats range from 2 to 3 millimeters in length, while the larvae are 4 to 5 millimeters long. The larvae of the fungus gnats are the damaging stage and feed on the roots. They are generally not a problem in greenhouse tomato and pepper, but can be a serious in cucumbers.	Biological control of fungus gnats is obtained through the use of predatory mites *Hypoaspis miles* and most recently *Hypoaspis aculeifer*. Both of these predatory mites also have activity against thrips larvae that move to the base of the plants to pupate. Nematode parasites in the genus Steinernema are applied as a drench to the root zone and kill the fungus gnat larvae by penetrating the larvae and consume them from the inside.

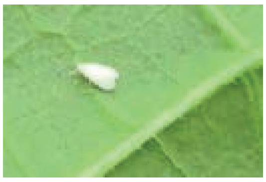
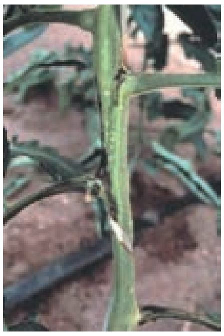
Name	Symptoms	Conditions for development	Specific control measures
White fly		Whitefly damage the plant by sucking sap from the leaves. Large infestations can cause leaf yellowing and a general decline in the plant. Sooty mold is commonly found in association with whitefly.	The parasitic wasps, *Encarsia formosa* and *Eretmocerus eremicus*, are effective against whitefly with parasitized whitefly scale becoming yellow or black in colour, depending on the parasite. *Delphastus pusillus* is a small beetle that feeds on whitefly eggs and is ideal for complementing Encarsia and Eretmocerus.
Bemisia White fly		The silverleaf whitefly (*Bemisia tabaci*) causes damage to plants through feeding and transmitting plant diseases. It feeds on host plants by piercing the phloem or lower leaf surfaces with its mouth and removing nutrients.	See white fly

Table 13

Main fungal and virus diseases disease in tomato.

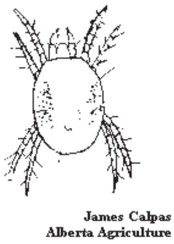
Name	Symptoms	Conditions for development	Specific control measures
Tomato Mosaic virus		ToMV is both seed and soil borne and can survive in the crop residue for up to two years. The symptoms of ToMV are often more severe under low light conditions, and the fern leaf symptom can develop on some of the resistant cultivars under low light conditions. The infected plants improve and grow out of the symptom as the light levels increase. There is no appreciable yield loss in most cases.	Control measures include the routine washing of work cloths and disinfection of pruning tools by dipping in a 10% trisodium phosphate solution. Completing a thorough greenhouse cleanup at the end of the crop year, growing in soilless substrates, and ensuring that the soil floors of the greenhouse are completely covered and sealed off with plastic serve to limit the year to year spread of the virus.
Tomato Brown Rugose Fruit Virus		ToBRFV is mechanically spread (crop maintenance, tools, packing, clothing). Bumble bees may play a role in dispersion.	Strong hygienic measures.
Pepino Mosaic Virus		PEPMv is easily mechanically transmittable. Can also be transmitted by drain water.	variation between varieties, hygiene, infection with weak virus.
Tomato Spotted Wilt Virus		TWSV is not easily spread by handling the plants. The primary vector of these viruses are thrips. Symptoms of TSWV and INSV include stunting of the plants and bronzing of the leaves.	The main approach to controlling this virus is through the control of the thrips vector.

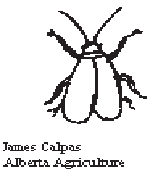
Name	Symptoms	Conditions for development	Specific control measures
Pythium root rot and wilt		The main conditions that predispose roots to infection by Pythium are physical damage to the roots and overwatering. Physical damage is really only a concern during the transplanting stage where the seedlings are placed into the production greenhouse.	Pythium takes advantage of plants under stress. Careful treatment of small plants during transplanting. Avoid waterlogging of plants and waterstress to maintain a healthy root environment.
Fusarium crown and root rot		Dead spots on roots, wilting of plants at high radiation levels. The fungus survives well in soil and can carry over one year to the next and can enter the greenhouse through holes in the plastic floor.	Infected plants must be carefully removed and destroyed. Do not reuse growing media from infected crops. Do a thorough clean-up of the structure between crops. Ensure that the entire greenhouse floor is securely covered in plastic and that there is no exposed soil.
Botrytis		Conditions of high relative humidity, over 85%, and the presence of water droplets on the plants favour disease development. Botrytis is quick to colonize wounds on the plant.	Avoid moisture on plants by condensation and/or drips from construction.
Bacterial canker		The disease is favoured by conditions of high humidity and is readily spread from plant to plant by splashing water, by infested pruning tools and by the day to day handling of the crop by workers.	Use disease free heat treated seed. Disease plants and adjacent plants should be removed as soon as an infection is discovered. Do not work the crop by moving from infected areas to healthy areas. Workers should wash their hands after working with infected plants.
Alternaria		Infection under humid conditions, wet leaf period for 4-6 h or more, temperature range 4–36°C, entry via fruits (damages), low temperature, small cracks.	climate, plant protection.

7.3.2 Management of pests and diseases of sweet pepper

Table 14

Main pests in sweet pepper.

Name	Symptoms	Conditions for development	Specific control measures**
Green peach aphid (*Myzus persicae*)		The green peach aphid (Myzus persicae) is the most common aphid pest of greenhouse sweet peppers but there are other aphid species that can become a problem in greenhouse peppers.	Introductions of predators and parasites may have to continue throughout the entire season. For best results always use a combination of aphid predators and parasites. Not all aphid biological control agents are equally effective on all aphid species so it is necessary to be sure of the identity of the aphid species in question. All of the species eventually develop winged forms. Consult your local supplier for information and recommendations on release rates.
The two-spotted spider mite (Tetranychus urticae)		The two-spotted spider mite (*Tetranychus urticae*) is a common pest of a number of greenhouse crops. Typical symptoms of two-spotted spider mite infestations include speckling of leaves and fine webbing on the underside of affected leaves. As the spider mite population increases, the leaves become brittle and brown in color, the amount of webbing on the leaves becomes very prominent and the mites can be seen milling about on the webs.	Effective biological control of the two-spotted spider mite is obtained by introducing the predatory mite *Phytoseiulus persimilis* as soon as two-spotted spider mites are detected in the crop. *P. persimilis* does well in the pepper canopy, and once established throughout the greenhouse it controls the spider mite population for the remainder of the season. The mites *Amblyseius fallacis* and *Amblyseius callifornicus* are closely related to *P. persimilis* and establish well and gives better control under low density mite situations, but should be used along with *P. persimilis.*
Trips		There are two species of thrips that are common pests in greenhouse vegetable crops, the western flower thrips (*Franliniella occindentalis*), and the onion thrips (*Thrips tabaci*). Thrips feed by opening wounds on the plant surface and sucking out the contents of the plant cells, the feeding results in small whitish streaks on the leaves and fruit and can cause distortions in the young developing fruit.	There are a number of predators available for biological control of thrips: predatory mites Amblyseius degenerans, Amblyseius cucumeris, Hypoaspis miles and Hypoaspis aculeifer and predatory bugs, Orius insidiosis and other Orius species.

Name	Symptoms	Conditions for development	Specific control measures**
Loopers and Caterpillars		At least two species of loopers have been associated with problems in greenhouse pepper crops, the cabbage looper, *Trichoplusia ni*, is the most common, with the alfalfa looper *Autographa californica* being an occasional problem. The damage is caused by the larval stages which can reach 2.5 to 3.5 centimeters in length depending on the species. The cabbage looper is the larger the two species in the final larval stage. The larva are a light green in color with whitish stripes along the length of their bodies. The larvae feed on foliage and fruit, fruit damage consists of holes in the fruit, accompanied by frass on and around the calyx. As the loopers reach their mature size, the amount of feeding damage can be considerable.	Screening intake vents will help prevent adult moths from entering the greenhouse. Pheromone traps can be used to detect the presence of adult moths in and around the greenhouse, and acts as an indicator for when to introduce biocontrol agents. Ultra-violet light traps are also used to catch adult moths. The egg parasite *Trichogramma brassicae* should be released as soon as adults are detected. The parasite *Cotesia magriniventris* should also be introduced, this parasite prefers to attack young loopers. Bacillus thuringiensis (B.T.) can also be used as part of the biocontrol program. B.T. is a microbial biocontrol agent which is activated once the loopers consume plant material which has been sprayed with B.T. Also, since the loopers are quite large, they can be removed by hand when they are found in the crop.
Whitefly		The greenhouse whitefly (*Trialeurodes vaporariorum*) is a common and serious pest in greenhouse crops However, it is rarely a problem on greenhouse sweet pepper. A second whitefly species, the sweet potato whitefly, *Bemesia tabaci*, has been found in some greenhouses Of the two whitefly species, the sweet potato whitefly is more difficult to control.	The parasitic wasps, *Encarsia formosa* and *Eretmocerus eremicus*, are effective against whitefly with parasitized whitefly scale becoming yellow or black in color, depending on the parasite. Scale parasitized by *Encarsia formosa* is black in color. *Delphastus pusillus* is a small beetle that feeds on whitefly eggs and is ideal for complementing Encarsia and Eretmocerus (Portree 1996).
Fungus Gnats		Fungus gnats are commonly found in practically all greenhouse crops. Fungus gnats are an indicator of moist conditions in the greenhouse and populations generally grow to be quite large early in the year or whenever there is pooling of water on the greenhouse floor. Adult fungus gnats range from 2 to 3 millimeters in length, while the larvae are 4 to 5 millimeters long. The larvae of the fungus gnats are the damaging stage and feed on the roots. They are generally not a problem in greenhouse tomato and pepper, but can be a serious in cucumbers .	Biological control of fungus gnats is obtained through the use of predatory mites *Hypoaspis miles* and most recently *Hypoaspis aculeifer*. Both of these predatory mites also have activity against thrips larvae that move to the base of the plants to pupate. Nematode parasites in the genus Steinernema are applied as a drench to the root zone and kill the fungus gnat larvae by penetrating the larvae and consume them from the inside.

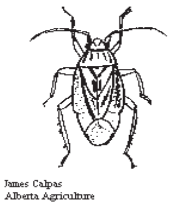
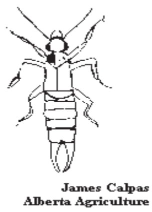
Name	Symptoms	Conditions for development	Specific control measures**
Lygus Bugs		Lygus bugs (*Lygus spp.*) are common pests of field crops, particularly alfalfa and canola, and have become increasingly important in greenhouse vegetable crops. There are a number of species within the genus which can become pests in the greenhouse including *Lygus lineolaris*. When nearby alfalfa or canola fields are cut or harvested, large numbers of Lygus bugs can be displaced and move into the greenhouse. Lygus bugs can enter the greenhouse through unscreened vents.	Lygus bugs are relatively large, fast-moving insects which can be difficult to control with biologicals. Orius and Deraeocoris will feed on Lygus bugs. Preventing the entry of Lygus bugs into the greenhouse by screening the vents offers the best prospect for controlling this pest.
Earwigs		The European earwig (*Forficula auricularia*) can be quite common in greenhouses. These insects are brown in color and about 10 - 15 millimeters long. They are easily identified by the presence of distinctive "cerci", or appendages located at the back end of the insect. In the male earwigs, the cerci resemble pincers, the cerci are almost straight on female earwigs. Earwigs are often found under the sawdust bags or rockwool slabs or hiding in other dark, moist, protected areas. Earwigs are nocturnal and feed on a variety of things, including plants and other insects.	Control of these insects is obtained by trapping them when they are still on the greenhouse floor, before they move into the canopy. Commercial traps and baits are available.

Table 15

Fungal and virus diseases in sweet pepper.

Disease	Info	Control
Damping-off	Damping-off is a disease of seedlings and occurs on the seeding table when the young plants are just beginning to grow. The disease is caused by a number of species of Pythium as well as *Rhizoctonia solani*. If the disease attacks the young plants as they are just emerging from the seed, the symptoms of this pre-emergent damping-off is simply seen as areas where no seedlings have emerged. Damping-off in young, emerged, seedlings is seen as a toppling over of the seedlings as the root systems are destroyed by the fungi. It is possible for some plants to be affected by these fungi and still develop into mature plants. If these plants are stressed later in the season the fungi can begin to progress in the plants causing a root rot which can eventually kill the mature plant	The best control for this disease is prevention, obtained by using high quality, fresh seed, and by maintaining optimal growing conditions for the young plants.

Disease	Info	Control
Pythium crown and root rot	Pythium crown and root rot caused by a number of Pythium spp. is not common in greenhouse peppers, however it can occur as an extension of an early damping-off problem in the seedlings or as a result of stressful conditions in the greenhouse at transplanting. Transplants infected by Pythium spp. develop slowly, are slow to root into and establish on the sawdust bags, and in extreme circumstances, wilt and slowly die.	The early stage of the crop cycle often determine the success of the entire year as it is important to go into the production cycle with strong, well established plants. The best method for the control of Pythium root rot is to ensure that optimal growing conditions, particularly root zone temperatures and watering, are maintained.
Fusarium stem and fruit rot	The appearance of soft, dark brown or black lesions on the stems at nodes or wound sites are symptoms of Fusarium stem and fruit rot caused by *Fusarium solani*. Black water-soaked lesions may also develop around the calyx, eventually spreading down the sides of the fruit. Under conditions of high humidity the fungal mycelium is quite apparent on the lesions.	Maintaining a clean greenhouse and good sanitation practices are key factors in preventing fusarium stem and fruit rot. Infected plants should be carefully removed from the greenhouse and buried in a landfill. Maintain good air circulation and avoid conditions where the relative humidity rises above 85%. Avoid wounding fruit and excessive wounding to the stems.
Gray mold	Gray mold, caused by the fungus *Botrytis cinerea*, is a common disease of greenhouse crops grown under conditions of high humidity and poor air circulation. The fungus enters the plant from wound sites and olive-green lesions develop that can eventually girdle the stem causing the plant to die. Fruit infections commonly begin at the calyx or at wound sites	Ensure good air circulation within the crop, maintain the relative humidity in the greenhouse below 85% and avoid the formation of free water on the plants and fruit.
Powdery mildew	Powdery mildew of greenhouse pepper, caused by *Leveillula taurica*, Yield losses of 10 to 15% are associated with the disease in these greenhouses.	Spots with a white powdery coating develops on the lower surface of the leaves, a slight chlorosis of the upper leaf surface is associated with the spots.
Pepper mild mottle virus (PMMV)	Pepper mild mottle virus occurs practically everywhere that pepper is grown. The presence of the virus is difficult to detect in the greenhouse until the plants begin to bear fruit. Leaf symptoms are easily mistake for other problems such as magnesium and manganese deficiencies. As the disease progresses in the plants, the new growth can be distinctly stunted with a clear mosaic pattern of yellow and green. Fruit symptoms often occur well in advance of the stunting symptoms and include the development of obvious bumps on the fruit as well as color streaking and green spotting as the fruit matures to color. Fruit tend to have pointed ends and may also develop sunken brown areas on the surface	Routine use of skim milk (100 gms / 1 Liter) as a dip while handling the plants acts to prevent any potential spread of the virus in the crop. The protein in skim milk binds to the virus and inactivates it. The virus is very stable in plant sap and it is easily spread from plant to plant. Once the plants begin to bear fruit, PMMV infected plants are fairly easy to recognize from symptoms on the fruit. Infected plants should be carefully removed and destroyed as the virus can survive in dry plant debris for up to 25 years. If all plants bear normal fruit, dipping the hands in skim milk can be discontinued.

Disease	Info	Control
Tobacco mosaic virus (TMV)	Tobacco is not a common disease problem. The symptoms of infection first appear on the leaf as a necrosis along the main veins accompanied by wilting and leaf New growth on the plants may exhibit mosaic symptoms as well as distorted growth	Use disease-free seed and ensure that resistant cultivars are grown. Use a skim milk dip when handling the plants and remove and destroy any infected plants that develop early in the season. Mature plants can be symptomless carriers of the virus and escape detection later in the season.
Tomato spotted wilt virus (TSWV)	Tomato spotted wilt virus has a wide host range, affecting approximately 300 species in 34 families of plants The virus is spread primarily by thrips, particularly the western flower thrips (*Frankliniella occidentalis*), and will only become a significant problem in greenhouse pepper crops if the thrips vector is present. Symptoms of infection on the leaves includes blackish-brown circular spots, or tan spots bordered by a black margin. Symptoms on ripening fruit are quite dramatic with orange to yellow spots surrounded by a green margin, or green spots on a background of the ripe fruit color of red, yellow or orange.	Control of this virus is obtained by controlling the thrips vector. Thrips biocontrol programs should be initiated at the beginning of the season. Weeds should be kept under strict control as they can serve to harbour both the thrips vector and the virus. Maintaining a 6 meter weed-free buffer zone around the greenhouse will help prevent the introduction of thrips into the greenhouse, as well as preventing the establishment of virus infected weed plants around the greenhouse which could serve as a source of the virus. Avoid having any ornamental plants in the greenhouse as they can also serve as reservoirs for the virus.
Tomato mosaic virus (ToMV	Tomato mosaic virus is not a common problem in greenhouse pepper and causes symptoms very similar to those caused by tobacco mosaic virus	Control measures are the same as for tobacco mosaic virus. Use disease-free seed and remove and destroy infected plants.

8 End of the growing season

8.1 Reuse of substrate

At the end of the growing season it should be decided if the substrate will be reused the next season If two cultures are grown in the same year it is most usual to reuse the substrate (tomato, cucumber). It is important to select and remove diseased plants before finishing the crop. A second crop on pathogen infested substrate is asking for trouble. After one season with two crops on the same substrate, it is highly recommended to start with new substrate. It secures a healthy start giving good production from the beginning onwards. Using the same substrate is possible if it is disinfected. In a second year the quality of the substrate is also less compared to new one. Due to the organic matter from dead roots in the slabs and to aits lower height, it is more compact resulting in higher water contents and less oxygen. So the irrigation strategy should be adapted.
The substrate leaving the greenhouse could be stacked in a container (Figure 36) to deliver for waste, depending on the local situation. Organic substrates (coir, peat) might be composted and reused as a compost elsewhere or it can be used to plough into field directly as soil improver It is important to remove the old substrate from the surrounding of the greenhouses to avoid pest and diseases to jump over to the new substrate and cultivation.

Figure 36 *Collecting used substrate in a container for recycling (stone wool) or composting (coir, peat).*

8.2 Cleaning the greenhouse

After finishing the crop the greenhouse has to be emptied. The following steps have to be taken:
- Remove all plant parts accurately and completely, including: string, chains.
- Don’t shred plant material (release of plant sap); don’t let it blow away.
- Avoid germination of plants from old fruit seeds.
- Put all plant parts outside in container with cover, remove container within 24h to garbage station.
- Avoid leaching of water from plants.
- Take out substrate, plastic foil, drip lines, floor covering.
- Use high pressure cleaner with hot water and bleach (50ppm) for cleaning paths and posts and troughs for cleaning.
- Clean greenhouse once more from back to front.
- Have an empty greenhouse for 3 weeks to let disinfectant work well.
- Clean driplines with pH 4 and leave it 24h, after rinse with clean water.
- Clean nozzles and pegs with submerging them in 10% tri-sodium phosphate solution (pH 13; 10 kg/100 L) for 24h.

9 Checklist

All items discussed in the previous chapters will be mentioned shortly in this checklist to be used before starting a cultivation, but also during cropping now and then. The checklist is mainly a short summary of the preceding chapters.

The actions are placed as far as possible in a chronological order but may overlap.

Tasks:
1. Decide on crop/cultivar.
2. Decide on substrate.
3. Clean and check facilities.
4. Order materials needed / delivery check.
5. Propagation.
6. Preparation of the greenhouse to receive plants.
7. Nutrient supply and registration.
8. Climate control and registration.
9. Irrigation control and registration.
10. Crop performance monitoring and registration.
11. Hygiene.
12. Plant protection plan.
13. Advice/Feedback.

9.1 Decide on crop/cultivar

To decide for a specific crop or cultivar it is necessary to get information on relevant cultivars and take into account the following aspects:
- Is there local advice from a breeder; trustworthy? Well educated? A person you can work with? Proper and timely advice may be valued as extra yield.
- What has been tested for a similar climate and growing system? Be wary of successes from a different climate and/or growing system.
- Yield and quality aspects. What price/profit can be realised?
- What varieties can be obtained?
- What are the most common local diseases, pests and viruses and which varieties are tolerant or resistant? Assess the local risks and do not choose the high yielding but vulnerable varieties.
- Is there an advice for cultivation of this particular variety? get a written and an electronic version. Breeders have often surprisingly detailed information for trusted customers.
- Is the cultivar adapted to the specific growing cycle that I am doing? Breeders have cultivars which are more suited for certain range of transplant dates than others for a certain climate. For instance, cultivars recommended in Almeria for an early transplant (beginning of August) differ completely from those recommended for a transplant by the end of September.
- Check for information on the internet, usually there is a lot of information available.

When starting with a new system avoid trial in situations which are known to go quickly beyond control. Do experiments in a well-known standard system and do not combine variety testing with other tests (substrate, irrigation etc.).

9.2 Decide on substrate

General considerations:
- Is there local advice from a supplier; trustworthy? Well educated? A person you can work with? Proper and timely advice may be valued as extra yield and risk management.
- How experienced are the greenhouse staff with the material?
- How easy is it to learn from other growers in the vicinity?
- What are the risks with new material? Are the risks known to the staff well before using the material and does the staff now how to handle those risks? Do they know which analyses and measurements are needed and can they get those?
- What is the security of delivery by the supplier.
- Do you get help about the growing system to be used?
- Are special plant raining methods required?
- What can I do with remnants at the end of the cultivation?

9.3 Clean and check facilities

For a proper functioning and long life of the greenhouse equipment, it is essential to perform a number of maintenance tasks, preferably in the period between growing cycles, when there is no interference with the crop, and more time is available.

9.3.1 Greenhouse plastic cover and insect screens

Check that there are no holes in the plastic and insect screens. If there are holes or large cracks, a good option is to use transparent sticky tape to close them.
If there is no rain between now and the next transplant, wash the dust accumulated on the greenhouse plastic film cover and machine wash the insect screens a couple of weeks before transplant, because light transmission can be much lowered.

9.3.2 Fog system

The most delicate element in the fog system are the nozzles. Even if RO water has been used, there is always a certain degree of clogging. A good practice is to remove the nozzles and then put them in a solution of vinegar (20%) and water (80%) for one hour or so. Then clean them with clear water and put them back on site, making sure they are properly installed back. Maintenance needs to other elements included in the system need to be addressed as specified by the manufacturer, this includes motor lubrication and dusting and pipes flushing. If the system does not have an automatic starting every night (to prevent Legionella), start the system at least once a week manually.

9.3.3 Shading/thermal screen

Ideally, it should be washed, but it is a very complicated task, especially for a non-permeable screen. Therefore, we do not recommend any maintenance task for the screen, except for opening and closing it manually a couple of weeks before transplant to make sure it will be working properly for the transplant. The whole screen must be inspected for holes and stretching; these must be mended and causes of uneven tensions and abrasion must be solved.
Maintenance further includes a visual check of all wiring and pulling systems to find places which are abraded, causes of uneven tensions and abrasion must be solved. The motors must be lubricated and dusted as indicated by the manufacturer.

9.3.4 Upper and sidewall vents

Make the motors run manual and check that windows can fully open. If that is not the case, then the sensor for final position of the window must be adjusted in the motor.
Maintenance further includes a visual check of all plastic to find places which are abraded, causes of uneven tensions and abrasion must be solved. The motors must be lubricated and dusted as indicated by the manufacturer.

9.3.5 Discharging debris

Once every two months, at the end of the cultivation cycle and whenever there were problems with nutrient precipitation, take of the end caps of every irrigation distribution line (or open the end valve if present) and allow water to flush debris in the irrigation water and pipework. Stop when the water is clear again.

9.3.6 Disinfection of the greenhouse

In general start by physically removing large particles before applying any chemicals or disinfectants; otherwise the problem will survive the treatment. Bring waste to garbage points or compost it, don’t leave it lying around the greenhouse (surviving of insects and fungi, attracts rodents). Physical means are brushing, high pressure water treatment, blowing, washing etc..

- Clean machinery after use in the work shed: lorries, boxes, tools can be cleaned with a high pressure cleaner and preferably hot water.
- Fence off clean and dirty parts of greenhouse to avoid cross contamination.
- Use a new floor cover for every crop cycle.

If the ground cover is kept on the ground it must be thoroughly cleaned (with attention to the gutter suspensions still in place) and then disinfected carefully.

- Use new substrate or steam sterilize the old one at minimum at 100°C for 15 minutes (slabs). Make sure this temperature is reached for the appropriate amount of time! This applies for all substrates.
- Avoid all animals: mice, rats, cats, dogs; in greenhouse. Avoid mice, etc. around the greenhouse by avoiding places where they can live (heaps of waste).
- Raise your plants in new substrate, transport them in clean boxes. If coming from plant propagator demand freshly disinfected boxes, especially polystyrene can harbour diseases in cracks. The latter has to be organised in the propagation but the grower must at all times take responsibility and action to get his plants safely in the greenhouse.
- If using own boxes for transport of plants: clean and disinfect those before use.

Chemicals to be used:

- Brinkman: Menno Florades (benzoic acid), long treating time needed. Good for buckets with knives which stand the whole night in the liquid.
- Virkon S (peroxy monosulphate): shorter treating time required, but admission in other countries unknown.

9.3.7 Maintenance of fertigation system

Once a year the precipitations in and on drippers can be removed using an oxidiser (to remove organics if present) followed by acid soaking (24 h) to remove precipitates of nutrients (like $CaSO_4$, $CaHPO_4$). Treat drippers and driplines inside and on the outside by soaking.

This can be done without removing the drippers by filling with acid. Outside cleaning can be done by using a moveable longitudinal container to soak complete drip lines with drippers (or combining inside and outside cleaning).

- If drippers are clogged with organic dirt rather than salts use a 3% bleach ($NaHClO_3$) solution or 6% hydrogen peroxide (H_2O_2) before nitric acid treating. Leave the solution 24h and after that period rinse with clean water. Do not use bleach (or peroxides) for special membranes in certain dripper types (pressure compensated) or ask your supplier beforehand.
- Clean driplines with pH 4 and leave it 24h, after that period rinse with clean water. When using nitric acid this is 2 to 3 litre (38% solution) per 100 litre.
- Then, to kill diseases, clean nozzles and pegs by submerging them in 10% tri-sodium phosphate solution (pH 13; 10 kg/100 L) for 24h after that period rinse with clean water.

Start with the main supply lines and then the smaller ones. Do not use your normal EC/pH meters but use indicator paper. Make sure solutions never can get in contact with the crop. Make sure all solution is removed from the lines before plants and slabs are in position by repeatedly flushing with irrigation cycles and checking the pH. Should sand or mineral dirt or shavings of plastic or metal ever get in the system do not hesitate to take out the affected drippers as these are lost.

9.4 Order materials needed

9.4.1 Materials ordered

Calculate numbers and make a list of all material needed for cultivation and order in time. Check list:

- Substrate.
- Plants (substrate, fertiliser, irrigation, crop protection).
- fertilizers.
- Clips, hooks, strings for trellising.
- Bumble bees.
- Plant protection products.

9.4.2 Materials delivered

Immediately upon receiving materials the shipment must be checked on:

- Proper type of material.
- Proper number of materials.
- Proper quality of material.

If any of the above is faulty, immediately inform the supplier in writing/mail even though no further action may be necessary.

9.5 Propagation

- Make clear and timely appointments with propagator.
- When using coir be timely (weeks before planting) aware of the calcium binding capacity of the material and the different irrigation strategy needed (adapted start and stop time). The proper washing of coir can only be done with the right analysis before and after the start (CEC and base saturation before starting and a slab analysis at the start and after 2 weeks). Ask the supplier for details.

9.6 Preparation of the greenhouse to receive plants

- Plant holes are opened on top of the stonewool. They may be circular or square depending on the tools used but allow all roots to grow into the stonewool.
- Drippers are placed on the slabs and are used to fill the slabs with a start recipe nutrient solution. NB This is not the regular recipe!
- A nutrient schedule for the start of cultivation, with calculated amounts of individual fertilisers, including acids.
- Registration of quantities and EC and pH.

Draining slabs
- After at least one night fully submerged, slabs are drained by creating two drain holes per slab at the lower side of the slabs at a right and left position, 1 cm away from the respective corners. The purpose of two holes instead of one is to prevent a part of the slab remaining water filled.
- Care must be taken to lift the slab slightly to start the cut at the bottom of the slab and then at least 2 cm upwards. This is necessary to prevent water logging by holes on a too high level and to prevent holes which are small enough to clog up during cultivation by roots or algae.

Planting
- Plants in blocks will be transported upright or laying horizontally on one side, not compressing on each other. Crates are recommended for horizontal transport provided there is enough distance on stacking to allow plants and blocks to not be compressed.
- Multilevel trolleys or any system ensuring there is enough distance to allow plants to not be compressed may be put to good use.
- Directly after transport, plants are transplanted on slabs, i.e. no storing in crates or trolleys.
- Drippers are temporary removed and plants are put on the slab after which the dripper is immediately put on the block.
- The stick and dripper pin may be inserted some cm into the stonewool but may not penetrate the slab at the bottom.
- Directly after transplanting the plants are irrigated to equalize the moist level of the blocks and to promote rooting from the blocks to the slabs.
- Irrigate with the required EC 2.5- 3.0 and pH 5.5.
- Special attention for the calculation of the water volume per m^2 and taking care that plugs stick out of the slabs.

9.7 Registrations

- The proper nutrient solution in mmol/L and recipe in kg A and B tank;
  - Was it OK?
- The registration of the supply of nutrients, analysis, handmeter registrations;
- Look back in registration forms to see if things went well or need adaptation:
  - Climate control setpoints
  - Irrigation setpoints
  - Other monitoring aspects
  - Pollination
  - Scouting of pests and diseases
  - Hygienic aspects
    - Satisfied with last year used products

9.8 Advice/ Feedback

One person in charge for nursery management, data collection, external advice
To make the cultivation a success it is a prerequisite that one English speaking person at the farm has the overall responsibility for the cultivation. This person has time and knowledge to oversee the developments at a daily basis and has a 24/7 responsibility of recognizing problems and has the ability to seek for solutions and the mandate to implement them. In case of absence a well-informed substitute has to be available.
A fixed internal worker takes measurements according to a schedule on fixed moments.
A fixed external advisor visiting the farm and giving feedback on a bi-weekly basis is recommended.

References

All information described originates from the extensive experiences of the authors in The Netherlands, Spain and from projects all over the world. It is adapted for Jordan conditions and for Jordan growers growing tomato and sweet pepper.

Authors recommend for further background reading:

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Annex 1 Fertilization in hydroponics

Fertilization in hydroponic horticulture

Technical information sheet No. 4 1

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Hydroponic fertilizers

In hydroponics, plant nutrients are supplied dissolved in the irrigation water. Usually irrigation water is delivered to the plant via drip irrigation. There are important differences between fertilization for soil and for hydroponic rooting media. Soil fertilizers may reduce growth by too much ammonium, urea, sulphates, bicarbonates or trace elements.

The A,B and C tanks

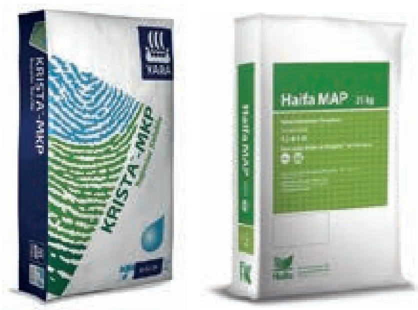
The fertilizers need to be dissolved in water before use. To limit the storage tank volume, stock solutions are concentrated, usually 100 times, less is possible. To avoid precipitation in tanks and in irrigation lines:

- Fertilizers are fairly pure.
- Water for dissolving is preferably pure.
- The A tank holds Ca fertilizer and chelate.
- The B tank holds all sulphates and phosphates and other elements and the trace elements.
- KNO_3 is divided over the A and B tanks in such a way that the weight of fertilizer in the A and B tank is equal.
- The C tank holds the acid.

Single fertilizers

Single fertilizers are used because:

- Cheaper than compound fertilizers.
- Accuracy of ammonium dose.
- Accuracy of individual trace elements.
- More flexible recipes.
- Slightly worse water quality can be used.

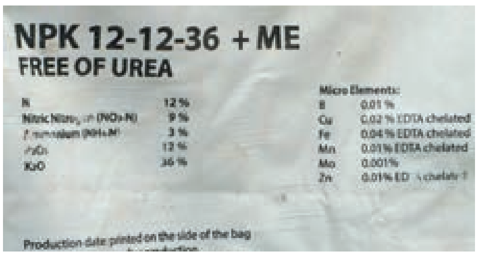


Compound fertilizers

Compound fertilizers can only be used if they:

- Contain no ammonium nor urea
- Contain enough N and K
- Contain no sulphate
- Contain proper ratio of trace elements (or none at all)
- Are complemented by using calcium nitrate

All in all only compound fertilizers especially produced for hydroponic growing are reliable.



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Fertilization in hydroponic horticulture

Technical information sheet No. 4 2

Irrigation Water Quality

It is recommended to use irrigation water with the following quality parameters:

- EC should be <1.0 mS/cm, because yield drops 5-15% per unit EC excess
- Sodium (Na) should be < 1.0 mmol/L, because yield drops 5-15% per excess mmol/L Na
- Sulphates cause precipitations
- Bicarbonates must be neutralized with acid
- Fertilizer dosing must be reduced for elements present such as Ca, Mg, SO_4, B etc.

Recipes

Each crop has its specific need for elements:

- Recipes need to be corrected for elements already present in the irrigation water.
- Recipes need to be corrected for 2-4 crop stages:
  - filling the substrate
  - initial weeks after planting
  - vegetative growth
  - generative growth
- Recipes for open and close systems are different!
- Close system starts with a special start recipe to saturate the substrate.
- There is difference in EC between supply (irrigation, root environment and drain:

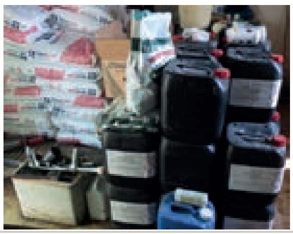
Crop	EC Root environment	EC Drain	EC Irrigation
Tomato	4	5	3.2
Cucumber	3.5	4	2.8
Lettuce	2.5		2.3
Lettuce winter	3.5		3
Sweet pepper	3.5	4	2.8
Egg-plant	3.7	4.3	3

Fertilizer calculation in kg/tank

To minimise the chance of not finding a required recipe, a certain order is used:

1. Add acids to neutralize bicarbonate & pH
2. Add ammonium as NH_4NO_3 or $NH_4H_2PO_4$
3. Add phosphates as KH_2PO_4
4. Add calcium as calcium nitrate
5. Add magnesium as $Mg(NO_3)_2$ or $MgSO_4$
6. Add Sulphates as K_2SO_4
7. Add potassium as KNO_3 and K_2SO_4

It is a good idea to use a calculator app:
http://www.wageningenur.nl/en/Research-Results/Projects-and-programmes/Euphoros-1/Calculation-tools/Nutrient-Solution-Calculator.htm



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