

Agrodok 23

Protected cultivation

Construction, requirements and use of greenhouses in
various climates

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Foreword

This Agrodok deals with the possibilities applicable to protect horticultural crops against unfavorable climatic conditions. It fits with the worldwide expansion of tunnels and greenhouses covered with plastic foils during the last two or three decades.

The development of sophisticated construction and climate control techniques justifies explanations on the more basic level. This Agrodok hopes to fulfill this target.

The writers are indebted to several reviewers, who offer valuable and helpful suggestions. Special acknowledgement is made to Dries Waayenberg of the Institute of Agricultural and Environmental Engineering (IMAG – DLO, Wageningen) and to Frits Veenman of Royal Brinkman B.V. in 's Gravenzande, for their valuable and constructive contributions, their criticizing, and suggestions to amplify the text.

We sincerely hope that this Agrodok will contribute to a worldwide development of intensive horticulture and will benefit a broad diversity of advisors and entrepreneurs.

The authors

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1 Introduction

The demand for an Agrodok on greenhouse cultures came from communities of farmers and market gardeners with small enterprises. Their need mainly concerns simple solutions to protect their crops using plastic film, in (sub)tropical countries as well as in the cooler mountainous regions of Africa and South America. We hope that this Agrodok will furnish this need.

In the near future, film will be used more and more and in very many forms too. It will mean that with little investments, farmers and market gardeners will soon be able to work more intensively and efficiently. This will enhance their cropping programme and the quality of their crops so that they can get a better market value for their products and, furthermore, reduce climatic risks.

People have always protected their crops from unfavourable climatic effects, from time immemorial. Shrubs and walls protect against the wind, foliage and slats against harsh sunlight and driving rain, and glass against the cold. The centuries-old practice in Europe of cultivation under glass placed at a 60° angle against a wall, can still be found in China near Peking. A similar sight can be seen in the highlands of Bolivia, where loam walls and plastic film shields at the sunside.

Glass is the material that has been used through the ages to let light into a greenhouse. The discovery of transparent synthetic film was a *groundbreaking* development. It made the building of a greenhouse very much cheaper. Since recent decades in many countries greenhouses and tunnels covered with plastic film are present. Indeed huge greenhouse complexes have sprung up in the highlands of East Africa and in the Andes region of South America too. Affluent countries build and supervise these greenhouses and local farmers who had sold their land to these enterprises become part of the labour force. They actually do learn about cultivation in greenhouses and, therefore, might possibly want to do this themselves independently later on, but then in a greenhouse that they could afford.

What such a greenhouse should look like depends on the type of climate. Should the crops be protected against the cold or also against

strong sun's rays? What should the ventilation capacity be or will a shade covering be the solution? Briefly, it is essential to first take into account the effects of the local climate when choosing a greenhouse and equipment. This is why we will start with a description of some very different climatic conditions, after which types of greenhouses and their constructions will be dealt with in subsequent chapters, together with regulation of the most appropriate greenhouse climate.

2 Requirements for greenhouse cultivation

2.1 Introduction

When choosing a greenhouse and necessary equipment it is vitally important to take the local climate into consideration. Before starting a greenhouse project one should carefully study the climate and the influences of the climate on the growth of the crops you are planning to grow. This chapter gives the principles of starting a greenhouse project, followed by a description of recording the climate and other pre-conditions for greenhouse cultivation. The chapter ends with the topography and the spatial infrastructure of the land.

2.2 Point of departure when starting a greenhouse project

Before starting a greenhouse project one must carefully check whether all requirements for its success have been met.

To do this you need data on the following:

- climate
 - soil and water
 - topography
 - accessibility of the area and the opportunities for transport and marketing
-
- As far as the climate is concerned, besides protection against fluctuating temperatures, protection is also needed against the sun's powerful rays (solar radiation), heavy rain, hail and strong wind. Crops often need to be protected against a combination of weather conditions such as these.
 - High standards will need to be placed on the type of soil, the soil profile and the location. Thus, if at all possible, choose soil with a good structure in a flat area for your greenhouse project.

- Pay careful attention to ensure good drainage of water to a lower area.
- It is very important to have enough and good irrigation water to irrigate and leach the soil.
- A good infrastructure for transporting materials and products is also of importance, just like the availability of electricity.
- Finally, you need to have insight into selling the products you want to grow and into the possibilities – if necessary – to switch to other crops.

2.3 Recording of the climate

To get good insight into the climate the average monthly figures of the different climate factors would generally be enough. This especially applies to *the rainfall, temperature, solar radiation and air humidity*. We will pay closer attention to this below.

First, we will take a look at these factors separately. However, to assess the climate of a certain area properly, we would then also need to study the interrelationship of these climatic factors. The climate data from the FAO (Food and Agriculture Organisation) database will serve as basis. Some of the different climatic conditions occurring across the world are presented in a figure at the end of this section.

Rainfall

An overview of the average monthly rainfall shows how the rain is distributed over the year (see Appendix 1 for some examples of rainfall distribution). We are mainly concerned with the dry and wet periods. If there is too much rain you would need to make certain of good drainage of excess water, from the greenhouse roof (gutters) as well as around the greenhouse (drainage). The water from the roof can be collected in a basin – for instance, lined with strong plastic film – for irrigation purposes. Sufficient storage capacity will help to better tide over the dry periods.

The rainfall usually varies year by year. High and low peaks could lead to problems. You will need to pay extra attention to drainage during extremely wet periods. And, for extreme drought, storage of irriga-

tion water is an absolute necessity. In subtropical and temperate climates hail and snow can cause damage. You will need to take this into account when selecting the covering material and the strength of the foundation.

When making decisions about building your greenhouse ensure that you are well informed about the rainfall, especially any extremes. This is so that you will be able to take the right preventive measures for the water supply, drainage and discharge of rainwater.

Temperatures

Plant growth is also dependent on the temperature. Each crop has its own temperature range within which it can grow optimally. The preferred temperatures of several crops are given in Table 1 below.

Table 1: Range of optimum growth temperatures of several vegetables

Crop	Temperature	Crop	Temperature
Tomatoes	18-23°C	Honey melon	13-18°C
Lettuce	10-18°C	Sweet pepper	18-23°C
Black radish	20-26°C	Cabbage	15-23°C
French beans	18-25°C	Egg plant	22-26°C
Paksoy	20-24°C	Cucumber	22-26°C

The above optimum temperatures can slightly deviate upwards or downwards without any serious damage to the growth. The upper limit of 28°C for tomato and sweet pepper means that ventilation should take place above this temperature (serious damage occurs only above 35°C) and cabbage and lettuce can withstand a minimum temperature of just below 0°C.

The wind-chill factor is also of significance to the plant. Low atmospheric humidity and much wind are likely to cause damage earlier. What should be taken into account is that a sudden rise or fall in temperature can occur in the course of time. Anyone who has already experienced this would be wise to ensure that the greenhouse is suitably

equipped to cope with this (see Appendix 1 for the maximum/minimum temperatures in °C of a few places).

Make sure that you have the correct information about the extremes of temperatures in your region, so that you have the necessary measures and equipment for climatic control of your greenhouse. It is also very important that you install the monitoring equipment to regulate the climate inside and outside your greenhouse. Indeed, prices also have a role to play.

Duration of sunshine

The growth and level of production of plants largely depends on the amount of sun that the crop gets per day. A reasonable yardstick is therefore the duration of sunshine.

A great many crops react to shorter or longer days (the so-called photoperiodicity of crops). This is why it is important that the day length over the entire year is known. You can lengthen the day using artificial light or shorten it by using blinds (e.g.: black plastic film). This is also mostly done in the tropics to make sure that the crops get through the required development stage (see Appendix 1 for the data on sunshine duration).

You need to know the day length to select the crop you want to cultivate. The total quantity of sun determines the growth rate and the level of production. The variation in the duration of sunshine is strongly related to the differences in day length. Furthermore, the annual rainfall pattern and accompanying cloudiness is also a critical factor. The topography of the country and especially the presence of mountains have an effect on the quantity of clouds.

Relative humidity

The humidity of the air, RH (relative humidity, see Glossary for definition), affects the growth and the health of the crops in various ways. A *high* RH, on the one hand, encourages fungal diseases, because under fluctuating temperatures and sharply increasing evaporation during the first morning hours, condensation can easily occur on the crop creating the ideal conditions for fungal spores to germinate rapidly. A high RH can also cause a crop to weaken and become more susceptible to changes in the weather, such as a sudden increase in evapora-

tion. However, there are far more ways in which a high RH can be controlled in a greenhouse than in open fields. For one, the crop does not get wet when it rains. Ventilation brings in cooler air with a low humidity and the RH will drop through heating.

On the other hand, a *low* RH can also be disadvantageous because then the transpiration rate will be too high. There are measures that can be taken like: sprinkling, screening and cooling. A low RH is an advantage in climates with high temperatures to enforce cooling. Differences such as these are decisive for good or poor growth of the crop (for examples of data on the average air humidity see Appendix 1).

Average RH values only give a global indication of the humidity. As a rule, the RH is highest early in the morning and lowest at midday. These are then the critical moments for regulating the climate in the greenhouse. Constant monitoring of prevailing conditions is therefore essential to be able to adequately regulate the climate in a greenhouse in response to changes in the RH.

Plants can get fungal diseases if the RH is high, so the climate in the greenhouse needs to be adjusted accordingly. However, a low RH also needs to be paid attention, because it usually occurs when the daytime temperature is at its highest. Monitoring the RH, therefore, is vitally important.

Speed and direction of the wind

Wind must not be forgotten when building greenhouses. If a certain wind direction is dominant, then it would be wise to build the greenhouse facing into the wind. The greenhouse construction will need to be anchored well especially if the wind speeds are likely to damage your greenhouse. The plastic film covering and particularly the ventilation system need to be protected against wind damage. A dominant wind direction can also seriously affect the ventilation. Moreover, this dominant wind direction must also be considered when placing windshields.

Ensure that your construction can withstand heavy winds and make certain that it is well anchored to avoid getting blown about by the 'vacuum effect'. In a windy climate you will need to choose a good quality plastic film.

Potential evaporation

Weather stations monitor the evaporation (see Glossary for definition) from a 'free' water surface by means of a so-called evaporation pan. It closely resembles the water loss from a crop that completely covers the soil and has an optimum supply of water, and therefore, these measurements are very useful data to the grower. The amount of evaporation is mainly determined by solar radiation. (Wind speed, temperature and RH also contribute somewhat). To monitor the prevailing evaporation from a crop what is important is the evaporation rate per day. This could rise to 6 or 8 mm in the tropics in the dry season and to even 9 mm in the arid subtropics (with a longer day length).

The evaporation inside a greenhouse is about two-thirds of that in the open air. The greenhouse cover and the construction elements intercept 20 to 30% of the radiation (the light), wind impact is virtually non-existent and the RH is generally higher. This is not possible if temperatures are somewhat higher. It is very important to keep the greenhouse cover clean! Evaporation will of course increase again by heating (see Appendix 1 for examples of potential evaporation rates).

An idea of the different types of climate across the globe is presented in Figure 1. The data consists of averages for the months December and June. It shows the different rainfall in millimetres, then the maximum and minimum temperatures for December and June, then the number of hours of sunshine per day, the air humidity (RH) and the potential evaporation (E_o) in millimetres per day.

Pay close attention to the climatic data in the different tables in Appendix 1.



Figure 1: Comparisons between different places in the world in December and June

1. Quito, Equador

	December	June
Rainfall	- 101 mm	- 47 mm
Temperature	- max 23, min 8°C	- max 22, min 7°C
Sunshine	- 5,52 h p d	- 5, 16 h p d
Relative humidity	- 69 %	- 67 %
Potential evaporation (Eo)	- 3,8 mm p d	- 3,7 mm p d

2. Lod Airport, Israel

	December	June
Rainfall	- 162 mm	- 0 mm
Temperature	- max 20, min 9°C	- max 30, min 17°C
Sunshine	- 5,95 h p d	- 11,97 h p d
Relative humidity	- 71 %	- 68 %
Potential evaporation (Eo)	- 1,6 mm p d	- 7,4 mm p d

3. New Dehli, India	December	June
Rainfall	- 9 mm	- 67 mm
Temperature	- max 23, min 8°C	- max 40, min 29°C
Sunshine	- 8,16 h p d	- 7,45 h p d
Relative humidity	- 49 %	- 38 %
Potential evaporation (Eo)	- 2,3 mm p d	- 8,5 mm p d 1.

4. Bandung, Indonesia	December	June
Rainfall	- 203 mm	- 59 mm
Temperature	- max 31, min 17°C	- max 30, min 15°C
Sunshine	- 6,44 h p d	- 7,56 h p d
Relative humidity	- 73 %	- 77 %
Potential evaporation (Eo)	- 5,3 mm p d	- 4,6 mm p d

5. Nairobi, Kenya	December	June
Rainfall	- 115 mm	- 29 mm
Temperature	- max 23, min 13°C	- max 22, min 11°C
Sunshine	- 7,96 h p d	- 5,85 h p d
Relative humidity	- 74 %	- 73 %
Potential evaporation (Eo)	- 4,9 mm p d	- 4,0 mm p d

2.4 Other requirements for intensive cultivation

Physical properties of the soil, moisture and groundwater

The moisture content in greenhouses is essential if one is to obtain the highest possible yield from the production. In addition, the permeability of the soil and the groundwater level also play a major role.

- Humus in particular, and clay/lutum to a lesser extent, retain water and are thus important constituents of the soil. Soil without any humus dries out rapidly and needs additional and regular watering.
- The greenhouse grower must drain excess water to avoid water logging. Good permeable soil is therefore the best.
- Furthermore, the groundwater level should be low (60-80 cm at the minimum below surface level) so that excess water can easily subside. If the groundwater level is high then the water will need to be able to flow to lower areas via drains.

The depth of the main rooting zone (topsoil) is dependent on the plant's needs for optimum root development. Generally, a topsoil of 40 to 50 cm in depth is adequate. It has to be able to aerate and drain well. There are dozens of crops that can root deeper.

Fertility can be increased by adding nutrients to the irrigation water for quicker uptake by the plants. If the soil has been under greenhouse cover for a long time the content of unabsorbable salts will increase. Furthermore, salination of the topsoil will also occur if frequently occurring stagnant surface water and ground water can only disappear from the ground through evaporation.

The degree of salination can be measured using an EC-meter (See Glossary for definition)

If leaching does not occur naturally by rainfall or is insufficient, then the soil must be leached with neutral water. **Leaching** is usually done with large quantities of water (200 to 300 mm), preferably portion by portion, to allow the salts to dissolve gradually. Next, it is important that the water can rapidly drain off deep via the ground water, taking with it the excess salts in solution. In shallow soil (with a high ground water level) an intensive drainage system is indispensable for effective leaching and discharging of drain water. If leaching of the soil presents insurmountable difficulties, the use of glass wool or rockwool as growing medium could be the answer. However, this would mean a more complex form of greenhouse cultivation that would necessitate the use of drip irrigation and added artificial fertiliser. Laying beds on the ground, consisting of coarse sand wrapped in plastic film, could be a compromise. Then any excess water containing salts could be drained off via the soil.

Take the permeability of the soil into account to avoid the occurrence of high groundwater, which can cause salination and damage the roots of the plants. The soil can be analysed in a simple manner to a depth of one metre by using an Edelman soil auger (see 6.6).

Chemical properties and fertility of the soil

Research is regularly carried out on soil fertility in laboratories for the benefit of modern greenhouse cultivation, involving chemical and

physical analysis of the micro- and macro-elements in the soil. This enables good advice to be given on the use of different types of fertilisers. The standard procedure is to measure the quantity of the most important elements such as:

- NH₄ (ammonia)
- K (potassium)
- Na (sodium)
- Ca (calcium)
- Mg (magnesium)
- NO₃ (nitrate)
- Cl (chloride)
- SO₄ (sulphate)
- HCO₃ (hydrocarbonate)
- P (phosphorus).

In addition, the pH (see Glossary for further definition), the acidity and the EC-value are also determined.

A large number of elements can be measured in the soil but also in water samples. Micro-elements that influence plant growth can also be determined, such as:

- Fe (iron)
- Mn (manganese)
- Zn (zinc)
- B (boron)
- Cu (copper)
- Mo (molybdenum).

Besides a complete, supplementary analysis can also be done during crop cultivation.

Get to know the quality of your soil to be able to apply fertiliser. If you have a big holding, then consider a contract with a laboratory for soil and water analyses to be able to make the right decisions about fertilising and fertigation (water and fertiliser combined).

2.5 Topography of the land

The size and shape of the plot partly determines where the greenhouse or tunnels can be built. From an irrigation point of view it is always advisable to build on horizontal terrain. It may also be wise to take any future extension of the greenhouse area into consideration at the outset. For surface drainage, gutters (outflow drains) or pipes are necessary with sufficient slope to lower areas from where water can be discharged to canals or rivers. The gutters can be covered or uncovered depending on the composition of the soil. For surface irrigation gutters are needed to transport the water to the plants. The slope determines the quantity and speed of the water transport.

Pay attention to the topography of your land. The greenhouse floors should be as horizontal as possible.

2.6 Spatial infrastructure and distribution

In view of the more expensive production equipment and the higher quality of the product it is important for you to consider the spatial location of your farm. Greenhouse cultivation needs more attention than outdoor cultivation (daily climate control, for instance). Therefore, you need to be within easy reach of your business at all times.

A good and accessible road will always be necessary for the transport of products and material to and fro. One should also be certain of the availability of irrigation water of a good quality. And, for further intensification of your greenhouse cultivation, connection to an electricity network is an important production requirement.

3 Greenhouses: types and constructions

3.1 Introduction

The way in which crops can be protected to promote growth and improve the growing period can vary between simple and inexpensive methods to complicated capital-intensive ones. There are several types of constructions and accompanying covering materials. We will limit ourselves to the constructions that are suitable for covering with plastic film and screening materials. We will also need to take into account the height and other needs of the crop.

3.2 Low constructions

The simplest form of cover is to lay sheets of transparent plastic film on the ground. To ensure that the plastic film cannot blow away, the sides are weighted down with soil. This is a method that can be used in areas with a moderate climate in the spring. By covering the seedbed a slightly higher temperature will be created and the moisture will be retained, which would improve germination and growth of the young plant. Immediately after transplanting you could also cover the ground like you would do with lettuce.

If you use perforated plastic film you could leave the cover for a bit longer when temperatures rise in the spring and take advantage of a little more accelerated growth. Furthermore, the exchange of gases can also take place so that the supply of CO₂ necessary for photosynthesis is not endangered.

Covering the ground with foliage or something similar is the cheapest method and something that is generally done in a sunny climate. A bit more structure can be added by a simple support and by placing screening material on top (see Figure 2). The young plants will then have some room to develop freely.

Often, a smaller construction with stakes can also be erected above the nursery beds on top of which plastic film or vegetable screening material can be fixed in place diagonally using wire, wood or bamboo. This offers protection – to a certain extent – against heavy rain and strong sun. Pay close attention to orientation with regard to the direction of the sun and prevailing wind (see Figure 3).

Open constructions such as these are most suitable for protection of the entire crop in the tropics. It will keep the



Figure 2: A simple support with screening material

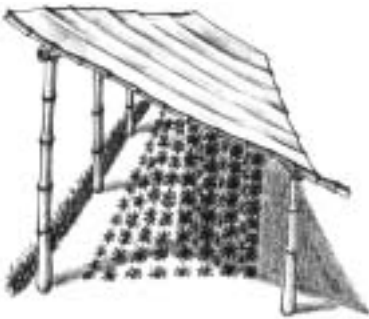


Figure 3: Protection against heavy rain and strong sunshine

plants drier and they will have less trouble with fungal diseases, so you will save on disease control. You will also get a better quality yield. To prevent the growth of weeds and to limit evaporation you could cover the ground with black plastic. The plants will then be planted in holes that you have made in the plastic. In greenhouses we use black-white plastic film. The white upper surface ensures the reflection of light, which is favourable for growth of the crop. It also prevents any sharp rise of the soil temperature when the sun irradiates on the plastic film. The protection of seedbeds and nursery beds against harsh sunshine, rainfall and from getting parched is essential for obtaining good planting material.

3.3 Low tunnels

Low tunnels and small walk-in tunnels are actually miniature greenhouses. A variety of types have been developed comprising of a semi-cylindrical supporting framework covered with plastic film. Figure 4 gives a few examples including measurements.

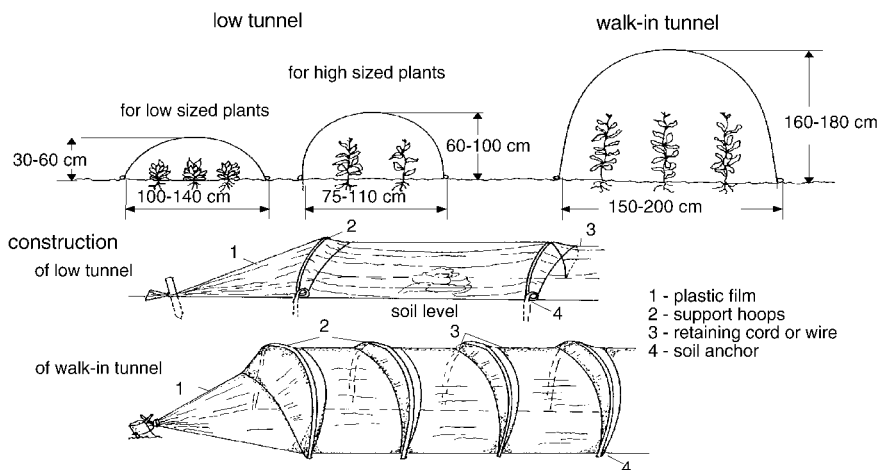


Figure 4: Low tunnels with measurements

The supporting framework can be made of hoops of wood, bamboo, plastic flexible tubes (as used for electricity wires) or strong wire. The hoops need to be placed at intervals of about 2 or 3 metres apart and anchored in the ground. After stretching the plastic film (for instance, polythene or PVC) over the hoops, the sides can be weighted down with a layer of soil. Further anchoring of the tunnel is done by a retaining cord or wire over the plastic film at each support hoop. For ventilation, the plastic film can be lifted up or shifted a little.

The plastic film is removed at harvest time and sometimes even earlier if the weather stays promising. Thus, the tunnel protects the crop in bad weather against low temperatures, hail and also from birds and insects. Low costs and a simple construction method are the most important advantages of low tunnels. The disadvantages are that they

only provide a limited temperature gain, opportunities for ventilation is very limited and caring for the plants (husbandry) is difficult. Low tunnels are usually used for only one crop. In most cases plastic film cover on the ground and low tunnels are the first steps towards protected cultivation. They could offer a temperature gain of 2 or 3 °C. For low-growing crops like lettuce, melon and the like, holdings often use low tunnels year after year as a proven remedy to force the crop.

3.4 Walk-in-tunnels

Man-sized tunnels covered with plastic film are high enough for working in and for accommodating taller crops such as tomatoes and cucumbers. The simplest form of the walk-in-tunnel is made of wooden or steel hoops over which the plastic is stretched. It is important to make sure that the plastic along the sides is anchored in the ground properly. The disadvantage of steel supports is that in the sun and at high temperatures the plastic film breaks down more rapidly where the plastic comes into contact with the hot metal. This can be avoided by insulating with strips of synthetic foam. Painting the plastic white above the hoops may help.



Figure 5: Walk-in-tunnel

The plastic film can be fixed in parts across the tunnel or in the length of the tunnel. Fixing across give the possibility to anchor the splits open for ventilation in between the length of the joints (see fig. 5).

If the length of the plastic film is laid lengthwise (longitudinally) a special anchoring is required at the end fronts, besides the side anchoring in the ground. The ventilation method, for such tunnels has to be linked with the construction and cladding system.

A simple tunnel has its limitations:

- In a warm climate, the simple means of ventilation limits the cultivation options.
- The use of cheap polythene (PE) film means that the covering will only last for one growing season because it will break down by the solar radiation and friction. This implies more costs for replacement and more refuse. Instead, you could buy UV-stabilised PE for a reasonable price, which will last a lot longer.
- Simple anchoring of the plastic film is vulnerable to storm damage.
- It is difficult to support tall crops properly.

Freestanding tunnels are used on a large scale. They offer a crop some protection against the cold and, especially for tall and vulnerable crops, also protection against the wind and rain. Experience has shown that limitations also arise as a result of excessively high temperatures and air humidity. Better ventilation is possible with some extra technical help, but it will also require some experience to be able to handle it.

3.5 Tunnels with opportunities for climate regulation

Long-time experience with the use of plastic tunnels has resulted in several improvements to do with climate regulation, cultivation options and the lifespan of the tunnel. Tunnels with a solid construction are illustrated in Figure 6.

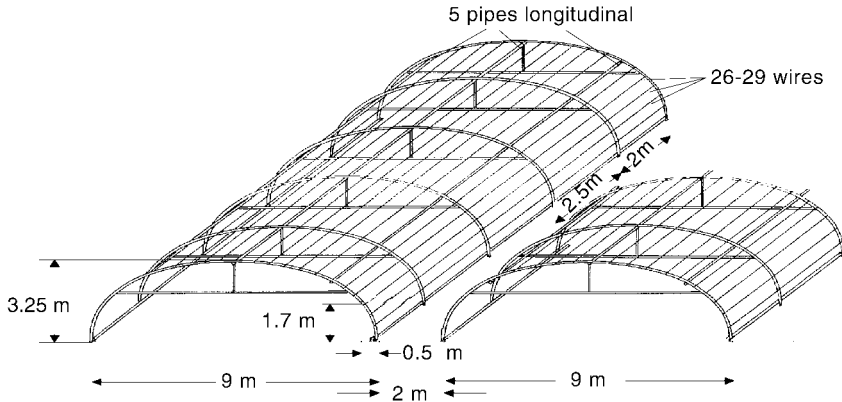


Figure 6: Tunnel with a solid construction

The measurements are such that they allow enough space for working in them and for growing a diversity of taller crops. The structure consists of galvanised tubing, which could even be reinforced with wires in the length. The intervals between the support hoops must be 2 to 2.5 metres to be able to withstand strong winds and the weight of snow. But, the disadvantage of steel hoops and wire is that the plastic film is likely to get damaged more quickly through friction where it touches the metal. Insulation with tape or with foam tape between steel hoop and film, can be very helpful. Cross supports (stability bracing) would be more robust and, furthermore, it offers the opportunity for supporting taller plants.

The step towards tunnels in which the climate can be better regulated is simply a question of money. However, investing in such a step will only be justified when the grower has had the necessary experience with the crop in mind and with the monitoring equipment that will be needed. Exchanging experiences with colleagues, special advisers and suppliers will be a step in the right direction.

In its simplest form, a multi-span greenhouse has a so-called flat-roof construction. This type of greenhouse is mainly found in southern Spain. The plastic film covering is usually of a simple PE quality and must be replaced after every 'winter crop'. The widths of the film are

laid down on the whole length of the greenhouse. Ventilation splits are made between the widths of plastic film. And, because it lacks a sturdy structure, tall plants are supported with poles. The construction in Figure 7 is more or less horizontal. Ventilation takes place via the cover by shifting the film.

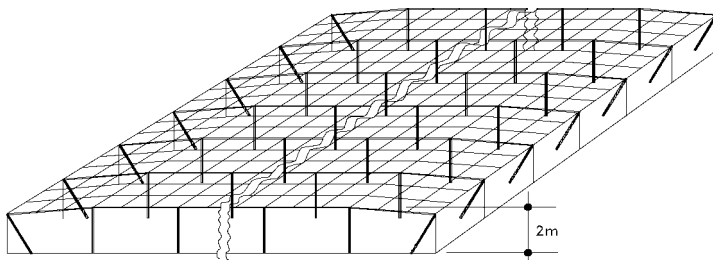


Figure 7: Flat-roof construction

Far more common are double-span tunnels, of which a variety of constructions have been developed. There are differences in the width of the bays and methods of shielding and ventilation (see Figures 8 en 9).

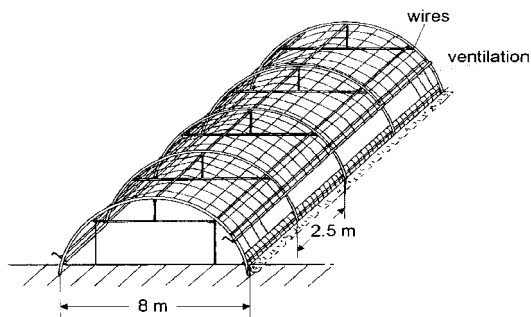


Figure 8: Plastic film tunnel showing cross section and roll-up side ventilation (also applied in double-span)

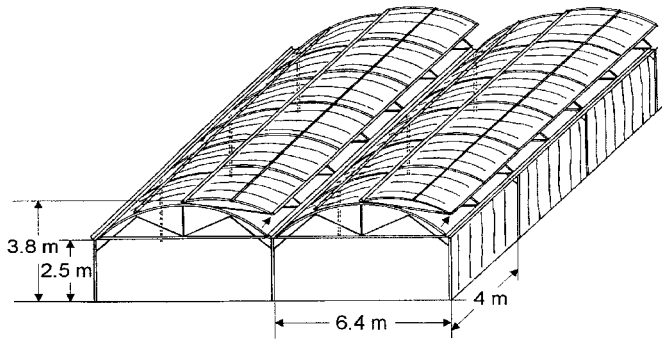


Figure 9: Double-span with roof ventilation by moving all or part of roof

Double en multi-span greenhouses are used to make better use of the space. Less marginal losses occur and working in them is more convenient and efficient. Regulation of the climate is done similarly as in the well-equipped single tunnels and can even be done mechanically and automatically. Other plus points are: more uniformity of the crop and more mechanisation possibilities, such as transport inside the tunnel. In the warm tropics the number of tunnels that can be built attached to each other is limited, because the ventilation via the sides is important and indispensable.

3.6 Shade halls

In regions with a dry sunny climate or in the dry season of a monsoon climate it is essential that the crops are protected against the blazing sun. A shade screen is usually placed above young plants, especially after potting or for cuttings. If this is going to be for a longer period, then a permanent screen will need to be placed. The easiest way would be to use leafy material like palm fronds, but woven cloth, netting or a lattice screen will last longer. Screening material vary in quality and in the degree to which they shut out the sunlight. The screening material can be attached to a construction of poles or tubing with squared horizontal brazing (see fig. 10). The construction can be anchored on the

sides for stability. Shade halls are used mainly in regions with prolonged blistering sunshine. Ventilation (cooling) occurs via the open netting of the cover on the sides. They provide the opportunity for growing a diversity of crops without the need for escaping to the more complicated cooled greenhouses.

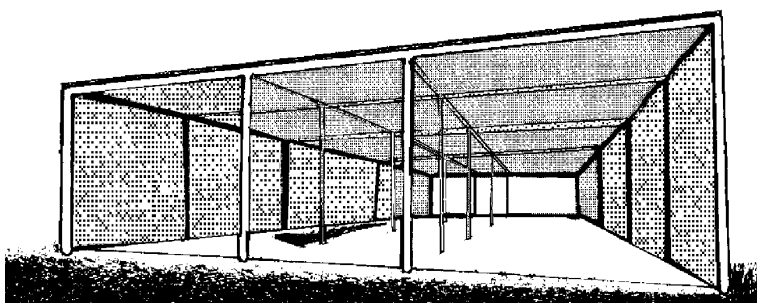


Figure 10: Shade hall (Rovero)

4 Greenhouse cover

4.1 Introduction

To protect the crop against influences from the outside, it is important that good quality material is used for the cover. This chapter discusses the advantages and disadvantages and the effects of various different materials.

4.2 Cover of plastic film

The plastic film most commonly used for soil cover and for greenhouse cover (cladding) is *polythene* (PE). Other plastic films are *polyvinylchloride* (PVC), *ethyleenvinylacetate* (EVA), polyester and *Tedlar* (see table 2). The advantage of PE over other plastic films is that it can be produced in all kinds of widths and thickness and is also cheap. One of the disadvantages is that its durability is limited. However, its lifespan can be significantly prolonged if it is UV-stabilised. The addition of vinylacetate when it is being produced, the EVA polymer, will improve the film's capacity to better retain the warmth in the greenhouse at night.

Very thin and thus cheap PE film of usually 30 to 50 microns thick (0.03-0.05 millimetres) can be used for covering the seedbeds and plant beds. To ensure that it does not get blown away the film can be anchored down with soil. Larger areas of the soil can also be covered with wider strips of film.

If you need to use the plastic film for a longer period and allow the covered crop to grow a bit more, then it would be preferable to use a *perforated plastic film*. To obtain 4 or 5 % perforation per square metre, 500 tot 1000 holes are punctured in the film mechanically. This will ensure that a good exchange of carbon dioxide and oxygen can take place and it will enable excess warmth to escape in sunny weather. Naturally, a small part of the warmth-retaining effect is given up, but the soil cover will still preserve the advantage of limiting transpiration losses.

PE film of 150 or 200 microns (0.15-0.20 millimetres) is mostly used for the covering of tunnels and greenhouses. The PE film can be produced in the same thickness as EVA. The better properties of this plastic film are clearly reflected by the higher price range. An overview of some of the properties of the above-mentioned plastic films is presented in the table below.

Table 2: Properties of plastic sheet materials

Type Price indication	Thickness in mm	Light transmission (%)		IR transmission	Durability
		90°	60°		
PE Very cheap	0.03 – 0.05	92	80	0.7-0.8	> 6 months
PE UV-stabilized Cheap	0.15-0.20	92	80	0.5-0.6	3-4 years
EVA Moderately priced	0.15-0.20	91	79	0.3-0.4	3-4 years
PVC Rather cheap	0.15-0.20	89	78	0.2-0.3	1-2 years
Melinex polyester Rather expensive	0.05-0.125	93	82	0.1-0.2	8-12 years
Tedlar Expensive	0.20	94		0.4	5-7 years

(Source: C. von Zabelitz, 1988, A. van Ittersum, 1997)

The value of light transmittance applies to new material. Through **ageing and pollution** the transparency of material gradually decreases. It can even mean a difference of 10 to 20 %. Light transmittance is highest when the sunlight is *perpendicular* to the greenhouse cover (90°). But, this is only for a small part of the day and the effect lessens as the sun drops towards the horizon. A value of 60° can be attached to light that comes into the greenhouse from various angles. When the sun is low the light transmission is far less as a result of substantial reflection losses. Thus, the amount of sun that can penetrate the greenhouse effectively is dependent on the orientation of the greenhouse.

The light transmissibility of the different plastic films does not differ very much, but the deterioration through ageing does. The transparency of polyester and Tedlar plastic film is maintained for a lot longer than the other films, but they are ten times more expensive than PE and PVC.

Light transmittance can reduce drastically by the formation of *condensation droplets* on the inner surface of the cover. This is why methods have been developed to prevent droplets from forming. After the plastic film has been given an anti-condensation (anti-fog) treatment, condensation will gradually decrease and will disappear completely in a year or two.

4.3 Effects of the cover materials

Light that comes into the greenhouse warms the soil, the crop and the construction. Reflection of *radiant energy* can be prevented by the film cover to a lesser or greater degree. As far as the so-called greenhouse effect is concerned, there could be enormous differences between the various films: PE retains heat but to a limited extent, EVA does it much better, while PVC and *Melinex* (see table 2) are exceptionally good and *Tedlar* has fairly good heat-retaining properties. Condensation has actually a positive effect on heat retention, especially when PE and EVA are used. The durability value of the film applies to a temperate climate. Under prolonged and blazing hot sunny conditions the film will last a lot shorter, especially PE en PVC. Experience with EVA film has been found to be fairly favourable under these conditions. Little is known about experience with the more expensive films.

A totally different recent development is the manufacture of film that has a certain cooling effect. The film *Astrolux* (not mentioned in the table) is specially made for regions where high radiation prevails. In greenhouses that are covered with this film mid-day temperatures can be kept 6 or 7° lower than under other types of cover (through high reflectivity). Of course, the price of this film is high and its use in small businesses seems to be a long way away.

Plastic film made of PE is usually used to cover the standard tunnels. In a warm climate the less heat-retentive qualities could actually prove to be advantageous because excess radiant energy can escape. If you really want to retain more heat and are looking for cheap covering, then PVC is a good choice. But, it would be better to choose EVA. Its better durability more than compensates for the higher price. The use

of the expensive *Melinex* is still limited and *Tedlar* is not yet in use because it cannot be supplied in good usable dimensions.

5 Climate control in the greenhouse

5.1 Introduction

The climate in the greenhouse is regulated by ventilating, heating and cooling and by using screening systems. If you try to regulate one factor then it usually has an effect on other climatic factors. For example, raising the temperature causes the relative humidity to drop. Ventilation affects the temperature as well as the air humidity, while screens affect the transmission of light (assimilation level) as well as the temperature.

Regulating the climate is most difficult during dry and sunny weather and, in particular, immediately following transplanting out when only a small portion of the ground is covered by plants. Transpiration of the crop has an important effect on the stability of the climate in the greenhouse. Excess transpiration demands much energy making sure that the air temperature does not rise too much and the air humidity increases. In the following sections we will discuss the different methods of controlling the climate.

5.2 Methods to regulate the climate

Ventilation

Ventilation is done by opening a part of the greenhouse cover in the sidewall, the roof or in the front or back entrance. In a warm climate the surface that can be opened for ventilation needs to be at least 20 to 25 % of the greenhouse hull (even more in the warmer tropics). Ventilating needs to be done when the temperature or the air humidity has risen too much, but also step-by-step to prevent sudden changes in the climate and a shock to the plants. Examples are presented in the figures 11, 12 and 13.

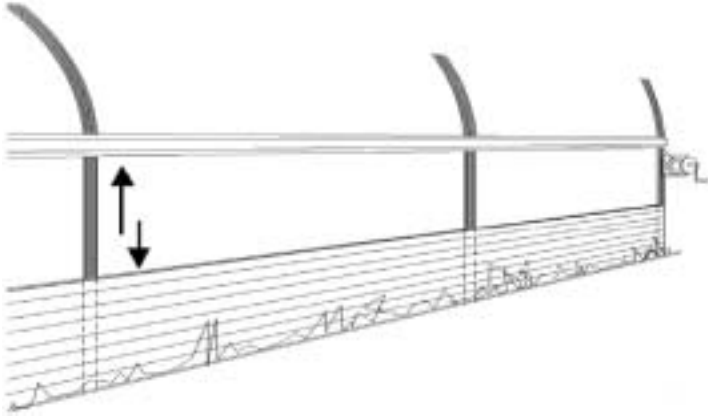


Figure 11: Roll-up sidewall ventilation at vertical part of hull

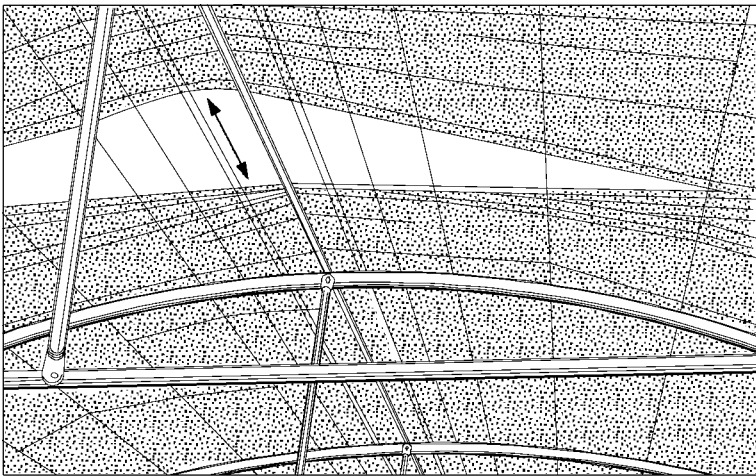


Figure 12: Ventilation system worked by pulling cords to open splits in a film-clad greenhouse

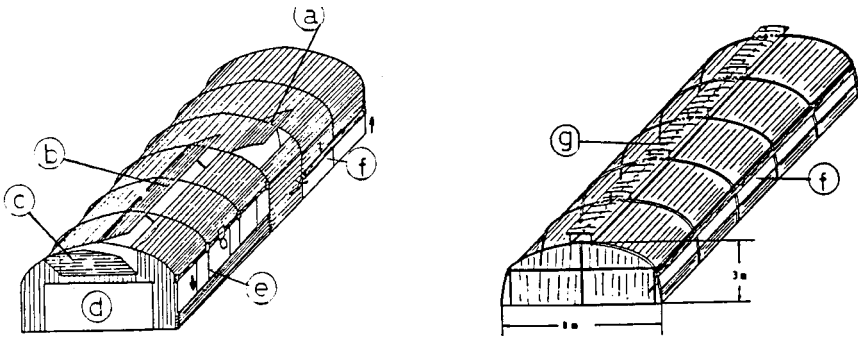


Figure 13: Overview of ventilation possibilities in plastic film greenhouses

Explanation:

a = simple ventilation window

b = continuous ventilation windows

c = ventilation window in entrance gable

d = ventilation through open door

e = side gable ventilation from above downwards

f = side gable ventilation from below upwards

g = continuous ventilation by lifting top windows

It would be handy if the windows (ventilators) can be opened and closed **gradually** by hand or mechanically. In extremely simple constructions you can just open the doors or make a permanent opening. There are very many possibilities to *ventilate manually*. Frequently and for ease, everything is just left open or partially open, but naturally this that does not provide for optimal regulation of the ventilation. In the better equipped greenhouses the ventilation (*mechanical*) is geared to the weather situation and the needs of the crop. This leads to more reliable results.

The warmth collects mainly in the uppermost part of the tunnel. Ventilation openings that are made here are therefore the most effective, but often make the construction of a tunnel more expensive. It is important that the windows are windproof, when closed as well as in the

varying degrees of being open. You could seal off the openings with insect netting.

Screens

Crops that cannot cope with too much sun need screening. This applies to shade-loving crops, but is also very essential above a seedbed and for raising young plants. Screening reduces evaporation somewhat, so that the water uptake of the crop can compensate for the loss of moisture. Otherwise, overheating of the plantcells could cause scorching or internal dehydration, resulting in blossom-end rot in tomatoes and sweet pepper, and tip burn in lettuce and cabbage, for instance. Finally, screens are desirable if the sun can suddenly surprise plants after a long period of dull weather. A movable screen can be very useful in intermittent sunny and cloudy weather.



Figure 14: A screen on the outside of the greenhouse

Obviously, screening is mainly needed in regions with a sunny and hot climate. The hotter the climate and more sensitive the plant, the more

it needs heavier screening. This is the reason why screening material is available in such a variety of shading percentages. Screens need to shield against a part of the radiant energy of the sun. Most effective is to place the screen on the outside of the greenhouse. Then, the part of the sun's warmth that it blocks out cannot warm the greenhouse, let alone the plants themselves.

However, an outside screen is more vulnerable to weather conditions and will also necessitate an extra construction on the greenhouse. Still, there are several solutions (see fig. 14). What is mostly done, especially in regions with a moderate climate, is to place a screen inside the greenhouse. This of course necessitates an additional construction, which can be realised inside a tunnel by means of extra wire supports attached to the framework (see fig. 15 and 16).

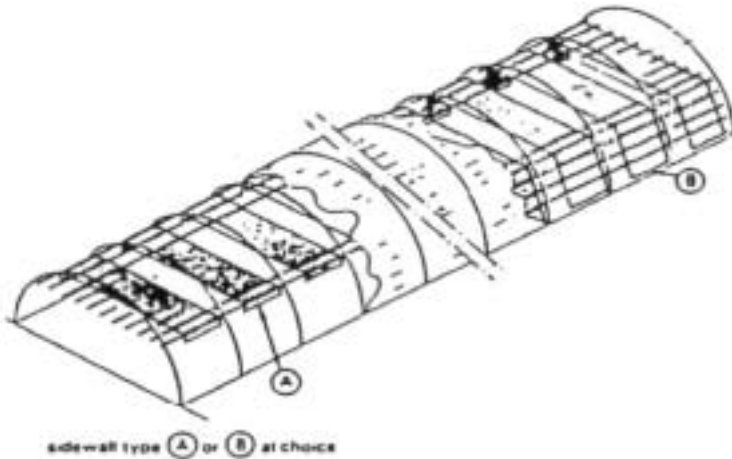


Figure 15: Screening inside a tunnel

In hot and sunny regions cultivation just solely under a screen system has come into fashion. Here, the screen material is supported on a foundation whereby ventilation can freely take place (see fig 10, shade hall). This is how cultivation is made possible on the Arabian Peninsula, for example.

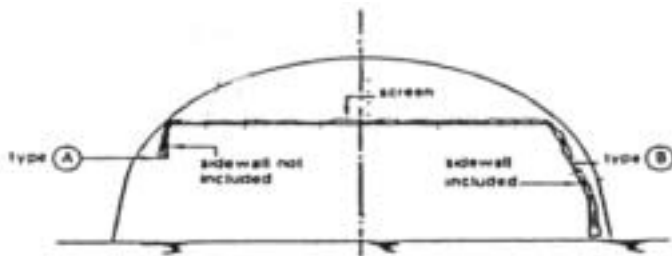


Figure 16: Screening inside a tunnel: cross-section

Heating

It is often necessary to heat the greenhouse or tunnel to prevent damage to the crop from the cold and to obtain optimum growth. Passive heating can be done by heat retention and actively by extra heating inside.

Passive heating

➤ **Cover of plastic film.**

Obviously, by covering the ground with plastic film and using tunnels and greenhouses a part of the day's radiant energy can be retained. This is thus a form of passive heating.

➤ **Heat conservation in water.**

A part of the sun's radiant energy can also be retained cheaply by placing black plastic film bags filled with water between the rows of crops on top of the soil. This water warms up during the day and gradually gives off its warmth to the greenhouse air. It is a pity though that towards morning, when the outside air is coldest, that the release of warmth is also at its lowest. This inexpensive method is, furthermore, vulnerable because leakage can easily occur.

➤ **Heat retaining plastic film.**

A better way to retain extra warmth is by choosing a more expensive plastic film for the greenhouse cover. This has already been discussed in Chapter 3. The more expensive EVA-film is what is most frequently used for this purpose. You could also use a double layer of film to cover the greenhouse or tunnel. The disadvantage of this relatively

more expensive method is that less light can be transmitted into the greenhouse so that growth is retarded.

➤ **‘Energy’ screens.**

‘Energy’ screens have also been used for a few decades to reduce heat loss during the night. Considering that one already has a screen to shield against the blazing sun’s rays, this can also be closed at night to keep in the warmth inside the greenhouse. There are screen materials that have been developed consisting of aluminium strips that can very effectively keep out the radiant energy, and as a rule these can also be used as shade screens. Of course investing in screens such as these is costly.

➤ **Reed mats.**

The practice of rolling out (reed) mats over the greenhouse cover for the night has been around for a long time, although it is labour intensive (see Figure 17).

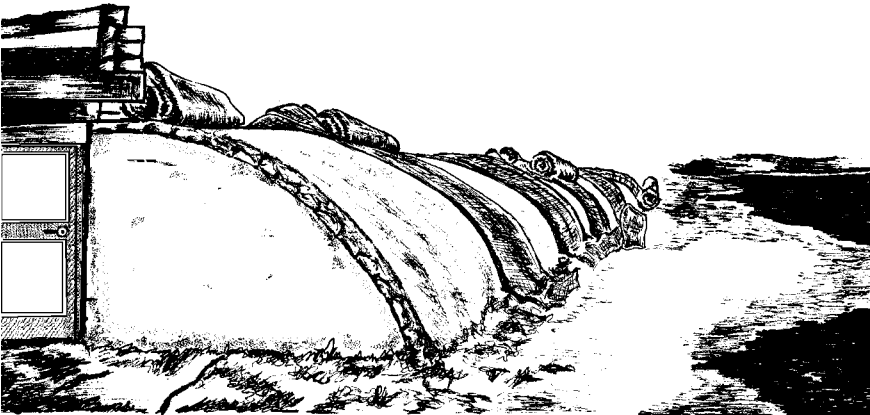


Figure 17: Reed mats placed over the greenhouse retain warmth

➤ **Hotbed manure.**

Another very different age-old method of heating the soil is by using hotbed manure. By piling up fresh straw-rich manure and covering it with layer of soil, microbial fermentation producing heat. Thus the temperature of the upper surface of the soil rises and this promotes

root development and growth of the crop. Furthermore, CO₂ is released, which stimulates the photosynthesis (see Glossary for definition). Adding straw enriched with nitrogenous fertiliser and then wetting it can speed up fermentation. Straw in bales can also be used. They should be covered with 15-20 cm greenhouse soil after making sure that the straw has been thoroughly wetted and soaked with a nitrogenous fertiliser. The temperature can rise to 30°C or more, dependent of course on the amount used per metre.

Active heating

Active heating of a greenhouse is also something that has been practised for ages.

► **Air heating.**

In its cheapest form, this is done by placing one or more heaters in the greenhouse and channeling the waste fumes upwards and out of the greenhouse via gradually ascending piping (see Figure 18). In this way you can try to get a certain degree of distribution of the heat output. In China they still use an ancient system in long greenhouses where a slightly sloping chimney runs all along the entire greenhouse, carrying the hot smoke from a stove burning in the front of the (lean-to) greenhouse. Naturally, the further away from the stove the lower the temperature gets.



Figure 18: The pipes of the stove heat the entire greenhouse

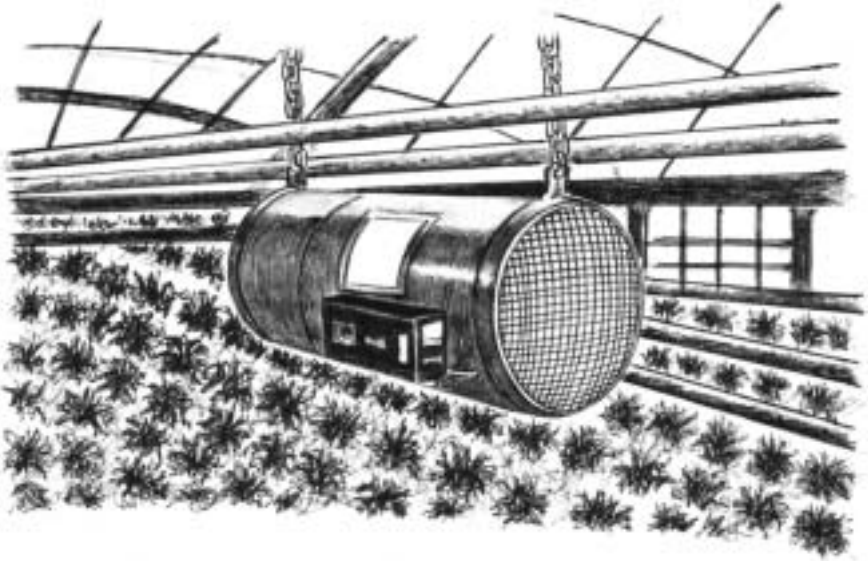


Figure 19: A hanging stove in the greenhouse

More modern stoves distribute the heated air all over the greenhouse. These can be small hanging stoves in which clean (sulphur-free, because sulphur dioxide is toxic for the crops) fuel is burned (like propane gas, for instance, see Figure 19). This of course does require the availability of electricity. The waste fumes containing carbon dioxide (CO_2) that is also useful for growth then remains in the greenhouse. If the greenhouse does not need to be ventilated assimilation can be boosted by this supply of CO_2 from the waste fumes as well as by a supply of pure CO_2 . Toxic gases, including carbon monoxide (CO) and methane (CH_4), are given off by incomplete combustion, which can cause serious harm to humans and crops.

In addition, there are standing stoves that disperse the heated air in the greenhouse by means of a fan, but carry the waste fumes out of the greenhouse (see Figure 20). Here, there is the risk of pollution via the greenhouse air. There is a whole range of them on the market.

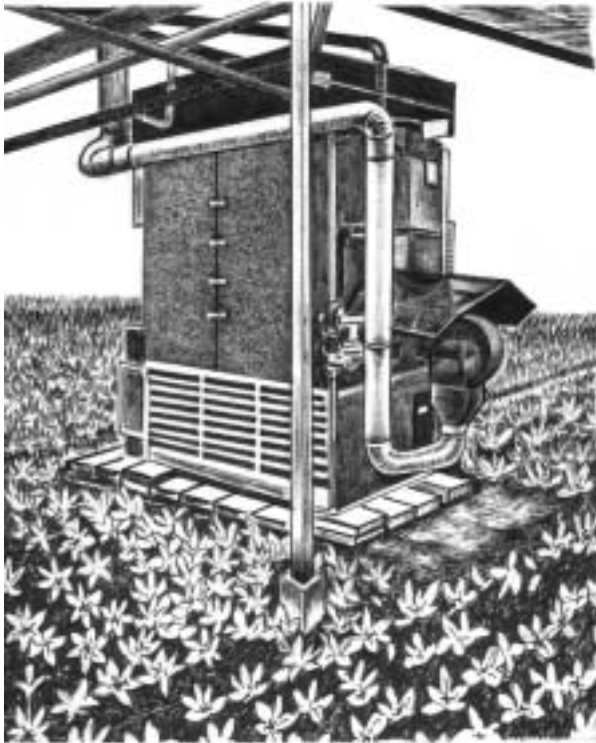


Figure 20: A standing stove

➤ **Water heating.**

Another principle that is applied is the use of boilers to heat water. The warm water will then be pumped around the greenhouse through pipes to give off heat evenly. Pipe heating can also be used if warm water is available from natural hot springs. Only in this case, the cooled (often salty) water must be discharged safely or pumped back into the ground again (see Figure 21).

To know how much heating capacity needs to be installed you need to have the climatic data inside and outside the greenhouse and the measurements of the greenhouse construction.

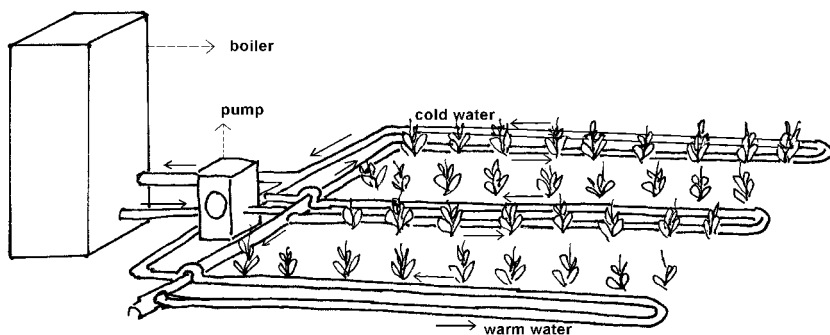


Figure 21: Warm water heating system

Cooling

If the radiation is too strong and the outside temperature is also too high, you can actively cool the greenhouse to improve the conditions for growth of the crop. In some cases cooling can be a supplementary measure, for instance coupled with screening or sometimes ventilation. Here below are a few examples:

➤ Sprinkling on greenhouse roof.

Well-equipped greenhouses sometimes have a sprinkler system that keeps the greenhouse roof wet when necessary. The small quantity of water with which the greenhouse roof is sprinkled in intervals evaporates in the warmth of the sun and cools the air around a couple of degrees. Ventilating with this somewhat cooler air ensures a better climate in the greenhouse. However, only pure rainwater is suitable for this purpose. River or spring water contains salts in solution, which will quickly and severely pollute the greenhouse as the water evaporates and the pollutants accumulate on the greenhouse roof.

➤ Wetting screen.

A sprinkler system that sprays water on the screen from underneath can offer some cooling. This is done in excessively sunny dry (arid) regions where cultivation takes place in a shade hall (see Section 5.1.2).

➤ **Pad and fan cooling.**

Under *hot and dry* weather conditions you could achieve an acceptable indoor climate in the greenhouse using a pad and fan system. It consists of placing the pads at one entrance of the greenhouse, so that the pads can be kept constantly wet by means of a sprinkling system. Ventilators (fans) at the opposite entrance draw the cooled and also moist air from the pads across the greenhouse and out of it. As the air flows through the greenhouse the sunlight gradually warms it up somewhat. The dryer the air the more effective the cooling is, since more condensed water can absorb from the pad. ‘Free’ ventilation is thus excluded. (See Appendix 1, Table 8 Pad and fan cooling). The pads can easily be filled with coconut fibre that keeps for several seasons. There are also manufactured pads on the market with a honeycomb structure, which remain intact for many years.

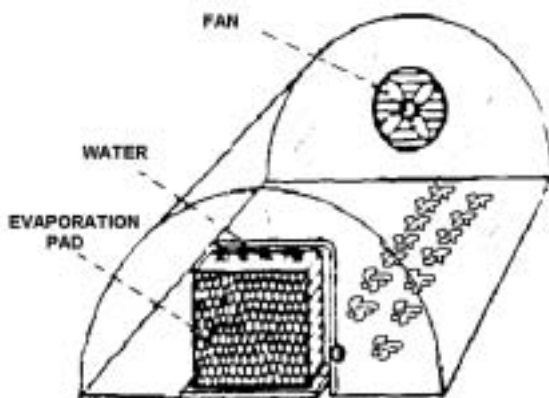


Figure 22: Pad and fan cooling

➤ **Sprinkling inside the greenhouse.**

On hot days or in a warm climate cooling of the greenhouse air can sometimes be done with a sprinkler installation, which can produce a satisfactory result. The use of clean water is an absolute necessity. However, certain crops like young plants/cuttings and crops that demand high air humidity do need to be protected with a mist installation.

Summarising the applications of climate control methods in a simple table:

Table 3: Possibilities of climate control in various types of ‘greenhouses’

	Ventilating	screening	heating	cooling
Plastic film ground cover and small tunnels	+/-	-	-	-
Simple walk in tunnels and greenhouses	+	+/-	-	-
Greenhouses with greater technical capacity	++	+	+/-	+/-

- not available
- +/- simple systems
- + good systems
- ++ advanced systems

5.3 Integration of the different elements of Climate Control

Thus far, we have discussed four ways in which the climate can be regulated in a tunnel or greenhouse, namely, by ventilating, screening, heating and cooling. How you do this depends on the crop’s requirements, the climate or the weather conditions and, naturally, on the type of crop cover and the construction of the greenhouse. A description of some simple monitoring equipment can be found in Section 6.6.

Plastic film ground cover and small tunnels

It is actually not possible to regulate the climate if plastic film is used to just simply cover the beds or the entire field. The plastic film must be removed before the temperature underneath it becomes too hot bringing with it the danger of scorching. However, if perforated film is used allowing some ventilation, then you can postpone removal of the film. Using film to cover the crops has a favourable effect on the air humidity. The germinating seed and the young plants profit from de-

veloping in a moister atmosphere. Moreover, the water loss will be limited, which is an advantage especially in dry weather conditions.

The smaller tunnels provide more opportunity for ventilation. The plastic film can be lifted up along the sides, for a shorter or longer period, and holes can also be made in the film so that better and permanent ventilation can take place. The plants will then be protected somewhat against the cold, wind and rain. When the crop grows and occupies more surface area (think of melons, for instance) remove the tunnel cover completely.

Regulating the climate by laying widths of PE-film on the ground or over small tunnels is rather limiting. Furthermore, this can be done only in the spring when the weather changes from cold to sufficiently warm. It also means that this form of protection can only be useful in temperate and subtropical climates.

Simple walk-in tunnels and greenhouses

When working in walk-in tunnels and greenhouses where taller crops are grown, you will have a better opportunity to regulate the climate, even if it would naturally depend on the construction and the technical capacity of the greenhouse. In any case a certain degree of ventilation is possible in simple greenhouses or tunnels. The climate in the greenhouse determines when and how much ventilation is needed so that you will need to have data on the temperature and preferably also the air humidity. Moreover, you will need to consider the demands of the crop.

Suppose that you have tomatoes or sweet peppers growing in a tunnel with side ventilation you can regulate. And, you also have sprinkling irrigation at your disposal. How would regulating the climate in the greenhouse turn out?

Measuring the temperature and the air humidity is done by means of a maximum-minimum thermometer and a wet-dry bulb thermometer, respectively. These instruments are best placed in a ventilated box. Readings are taken several times a day during which particular attention needs to be paid to the sunshine and clouds. To gain insight into the weather effects it is essential that these observations are done with strict regularity, for example, taking the reading of the thermometers

outside the greenhouse at 7 a.m., 12 noon and 5 p.m. This needs to be done far more frequently inside the greenhouse. It can be done much simpler if you have a thermo-hydrograph to do the recordings. Thus, armed with the insights you gain from all of this and paying attention to the requirements of the crop, you will be able to regulate the climate.

Ventilation is done whenever the threat of an excessive rise of temperature and the air humidity arises. The air humidity can also be reduced by ventilation, when sprinkling with water should be done, if all possible.

Let us take a look at how such a day would look like:

- *Early morning hours - It is a sunny morning the air temperature rises and the crop starts transpiring a lot also raising the air humidity in the greenhouse. Although the temperature of the air rises, parts of the plants such as fruits and thicker branches are heating up slower, while the rising humidity can reach the condensation point and some moisture can affect those plant parts. Condensation also occurs more easily underneath the crop. And, condensation promotes fungal growth. This is why you must ventilate some 25 % even if the temperature is not so high.*
- *Later in the morning - If it becomes warmer, for instance, above 25 °C, then you ventilate using 50% of the available capacity. If the temperature continues to rise to 28-30 °C, for instance, then ventilate a whole 100%. Windows that can be opened in several positions are perfect for stepwise regulation of the ventilation. This also applies to the rollable parts of the sidewalls and openings that can be open as much or little as needed (see Section 4.2 Ventilation).*
- *During the day - Now, the weather will play its part in making the air humidity drop sharply while the temperature rises. Next, you need more help: moistening the greenhouse air and/or the crop so as to raise the air humidity. How do you set the marginal values? The higher the temperature the sooner the marginal values are reached. Thus, at an air humidity of 40% and a temperature of 25 °C it would be about as 'dry' as 60% air humidity at 30°. A small amount of sprinkling water, say half a litre per square metre or less,*

is adequate to moisten the crop. Even just keeping the paths between the crop wet could be enough. You would need to use the water sprinkler if the crop is young and has not achieved full ground cover. Transpiration from the crop contributes little when the air humidity increases. More difficult is controlling the ventilation during intermittent cloudy weather. The temperature under these conditions can alter by 5° within 5 or 10 minutes. Best is to keep track of the outside temperature, and to reduce the ventilation to a quarter or half of the capacity.

- *Late afternoon - Ventilation can then be done stepwise once again in de afternoon and evening.*
- *Night - If it continues to be warm, it would be advisable to continue to ventilate.*

In a climate where it stays warm night after night, the doors and windows ought to be kept open all the time.

Climate control as and when needed could be done even in the simplest of tunnels. Pay good attention to the temperature as well as the air humidity. Often one is inclined to start ventilation in the morning too late because the temperature in the greenhouse is still not very high. But, the humidity can rise rapidly, especially if the crop is fully grown, which would lead to a wet crop that is susceptible for fungus diseases. Besides, try to avoid causing shocks to the plant by sudden changes in the temperature and air humidity.

Greenhouses with a greater technical capacity

If we can screen and heat greenhouses and tunnels besides ventilating them, then we have at our disposal more advanced means of controlling the climate. These means will enable better correction of temperatures that are too low or too high. Investing in them brings with it the more expensive monitoring equipment. Detailed discussion of all the possibilities available cannot be done in the space available, and therefore, here are a few comments to add to what has already been said in Section 5.2.

The primary aim of heating a greenhouse is to obtain the best possible temperature for the growth of the crop. As a guideline, follow the optimum day and night temperature that applies to the crop in question.

If a screen is present, then it can be shut to save on heating costs when the nights are cold, and to protect against an excessive increase in temperature when the sun is hottest. When screening take particular care that you do not obstruct the ventilation too much.

A rising temperature reduces the air humidity. Air humidity that is too high can therefore be counteracted by a little heat. This prevents fungal infection from occurring. Furthermore, heating and ventilating at the same time is done to decrease the air humidity and stimulate evaporation during periods with dull weather. This leads to sturdier and more balanced crop growth.

If you have heating at your disposal as well as good controllable ventilation, then it pays to know the requirements of your crop. It is also advisable to exchange experiences with colleague growers. The improvement of production standards and quality is, after all, of mutual interest to all growers. Thus, do not look upon your colleagues as competitors, but as fellow growers. Good monitoring equipment is indispensable. Once you have learned to control the climate well by measuring (and recording), then the use of mechanical monitoring equipment will be getting nearer your reach.

The more aids there are to influence and control the climate in the greenhouse, the greater the demands placed on the expertise of the grower. Besides one's own knowledge and experience, the help from advisers, consultation with colleagues and support from the supplying industry is vitally important. Investing in greenhouses and equipment is thus only purposeful if you have access to adequate support (advice and service) to be able to deliver a high quality product. It also applies to cultivation in greenhouses with fan and pad cooling.

The most modern and most expensive methods for climate control involves using sensors coupled to a computer with graph recordings. This offers huge advantages and is also the basis of automatic climate control.

5.4 Reactions of the crop to regulation of the climate

In general, the temperature and the air humidity of a greenhouse are higher inside than outside. In particular, a higher temperature at night is better for warmth-loving crops like sweet pepper and cucumber. In addition, the plant benefits from the slightly higher air humidity during the day (there is less water loss from transpiration than outside) and thus there is less stress to adversely affect plant growth. This results in quicker growth, larger leaves and more height and a better fruit setting.

The plant cools itself by transpiration. When the water uptake by the roots is sufficient for transpiration the temperature of the crop will be more or less the same as the surrounding air. If the water uptake is not optimal, the temperature of the plant will obviously be above that of its surroundings, sometimes even 5 – 10°C higher. This causes damage to parts of the plant. Protecting the crop by means of a greenhouse cover will produce a healthier crop: no damage from the wind and heavy rain, no washing off of pesticides, no leaching of fertilisers.

6 Water supply and crop protection

6.1 Introduction

As there can be no access inside a closed greenhouse to rain from the outside, it is extremely important that the crops in the greenhouse have their own water supply. The quantity of water can be adjusted to the crop's needs. Moreover, crops inside greenhouse are better protected from outside influences. This chapter addresses water supply and crop protection in the greenhouse.

6.2 Water supply and fertilising

Plants cannot benefit directly from the rain when they are grown inside a greenhouse and should therefore be supplied with water by artificial means. First of all it is important to know how much water a particular crop needs. Then, you need to have an idea of how much water can be supplied by the system you are using. We will delve deeper into these two aspects here.

Transpiration and evaporation

While plants need water mainly because of the transpiration, they also use 5 to 10 % of the water for their growth. Plants transpire to cool themselves and to encourage transport of the minerals that the roots have absorbed. The amount of transpiration is chiefly determined by the sun. Other factors of less importance are the temperature, the air humidity and the wind speed.

The light intensity is much lower inside a greenhouse than outside it. Roughly two-thirds of the light from the outside penetrates into the greenhouse because the material covering the greenhouse and the shade from the construction elements restricts the light transmission. As far as the other factors are concerned, the wind speed inside the greenhouse is much lower than outside and the temperature is higher. For ease we can ignore these two. Then, the transpiration level inside the greenhouse remains about two-thirds of the level outside it.

Transpiring is not always optimal. Transpiration is a hundred per cent if a crop is fully grown and the ground fully covered. However, a crop that is still growing does not always transpire to its full potential. Take lettuce, for instance, with its growth period of six weeks. The young crop transpires far less than a hundred per cent, but there is also water loss directly from the exposed soil in between the plants (evaporation). We can estimate the total water loss (transpiration + evaporation) for two weeks at 50 per cent. If the lettuce is half-grown, then the total water loss for the two weeks comes to 75 per cent. The full 100 per cent transpiration + evaporation only takes place during the last two weeks of growth. A similar calculation can be done for other crops with a different development pattern.

An indication about the level of evaporation in the various different climates and seasons can be derived from the data in Section 2.3 'the potential evaporation'. You should continue to pay attention to the prevailing weather conditions over the past days. By taking into account the development and the cultivation period of the crop you can make a good estimation of the total water needs of the crop for the entire duration, and also the maximum needs per day. Just how big an area can be cultivated at one time (greenhouse area) can then be ascertained based on the capacity of the water source and/or the water storage capacity.

Leaching

There is another reason why we need irrigation water. We need to leach the soil after each crop has been harvested. During cultivation nutrient salts are absorbed by plant roots from the soil and 'ballast' salts, such as sodium, natriumchloride (NaCl) and sulphates are left behind. When water evaporates from the soil these ballast salts accumulate in the topsoil, just where most of the roots are. If these salts were not removed by leaching, then the plant's water uptake would become more and more difficult because the ground will gradually turn salty. This is an age-old problem in many irrigated areas in dry and warm climates, and one that certainly applies to greenhouse crops. A substantial amount of water is needed (200-300 mm, which equals 200-300 litres per square meter) is required to achieve thorough leach-

ing. Leaching also implies making sure that the water containing the salts is actually carried away. This means that a drainage system is essential, unless you have coarse sandy ground underneath the rooted soil through which no significant capillary rise can take place.

Table 4: Relative crop tolerance to salts in the root zone of crops grown in open ground

High tolerance EC x 10,000 = 12	Moderate tolerance EC x 10,000 = 10	Low tolerance EC x 10,000 = 4
Beet / beetroot Asparagus Spinach	Tomatoes Broccoli Cabbage Sweet pepper Cauliflower Sweet corn Potatoes Carrots Onions Peas Pumpkin Cucumber	Radish Celery Beans
EC x 10,000 = 10	EC x 10,000 = 4	EC x 10,000 = 3

(Source: Saline and Alkaline Soils. USDA Agricultural Handbook No 60. pp 67, 1954)

High tolerance rates: EC = 12 - 10

Moderate tolerance rates: EC = 10 - 4

Low tolerance rates: EC = 4 - 3

The irrigation system should also have the capacity and water source and storage capacity to be able to cope with flushing of the greenhouse soil. As the greenhouse crop will need a great deal of irrigation water, it would be very wise if you were to ensure that the rainwater that falls on the greenhouse does not get wasted. Collecting the rain-

water from the greenhouse roof via gutters and stored in an adjacent basin would therefore be most valuable.

You could use plastic film to line basins to catch the rainwater. Growers in many countries make as much use as possible of the rainwater they store in basins. After all, rainwater is good quality water and the quality of the water is of the utmost importance. Growers benefit from using water with a low concentration of salts in solution because then they would need less water for leaching.

The concentration of salts is expressed by EC (electrical conductivity) and can be measured with a simple EC meter. A high EC indicates a high salt content. The quality of water is top priority because crops react to even a tiny concentration of salts, which causes a reduction in productivity. Table 4 shows the tolerance of several crops to salts in the root zone.

Also of importance is knowledge of the acidity of the water, expressed as the pH of the water. If the pH is below 7, then the water is acid; if it is above 7, then the water is alkaline (pH 7 = neutral). Plants respond best to water that has a pH of between 6 and 7. You can measure this with a pH-meter.

6.3 Methods of supplying water to the crop

The methods by which crops in the open field are supplied with water also apply to crops in greenhouses. You need an irrigation method that is reliable and one that works very evenly. Here below are a few possibilities:

- By far the simplest method is to pour water in channels or onto flat fields that are surrounded by small dykes. Do ensure that the water is evenly distributed
- For rowcrops you could use black PE-film hosepipe that has small holes of ca. 2 millimetres. The soil needs to be flat or may slope very slightly towards the ends of the tubing. The length of the hose may be 20 to 30 metres. The water pressure must be ca. 0.2 ato (2m)

- Sprinkling using permanent pipes is widely used in greenhouses. The pipes could be placed underneath the crops, which in climates with high air humidity would be a good idea. Then, the plants would not get wet so there would be less chance of fungal infection. You could also irrigate the rowcrops in strips and keep dry the paths for walking on. But, in most cases the pipes are placed above the crops. To make sure that the plants do not remain wet at night irrigation should be done in the morning. The sprinkling system can also be used to moisten the crop when the weather is sunny and very dry, thus having a cooling effect, increasing the relative humidity and reducing the transpiration.
- Drip irrigation is rapidly on the increase in greenhouse cultivation. Here, the plants get water individually. The soil needs to be flat and the water clean because the small droplet openings must not get blocked. It is very desirable that the system has a good filter at the place where the water enters it. Many drip irrigation systems work on a low water pressure of 1 or 2 metres water column, for instance. This can be achieved very cheaply for a small system by means of a WC-float at the beginning of the main pipes. Usually, fertiliser in solution in the correct dosage (fertigation) is administered when drip irrigation is done. As opposed to sprinkling and watering, you can save 30-70% of your water through drip irrigation, especially in a very dry climate. Check the capacity of your sprinkling units once you have installed your irrigation system.

Check to see if the water output at both ends of the pipes is equal, if not try to adjust it by choosing other spraying openings. Check the system regularly for blockages and set it right straightaway.

The supply of water supply to greenhouse crops calls for much attention. You as grower can optimise this water supply yourself. You will need to establish when and how much water would be needed to suit the weather conditions and the development of the crop. Determine beforehand the capacity of the watering system and check it regularly for defects. Check whether the entire rooting zone is moist after a round of irrigation now and then using a soil auger.

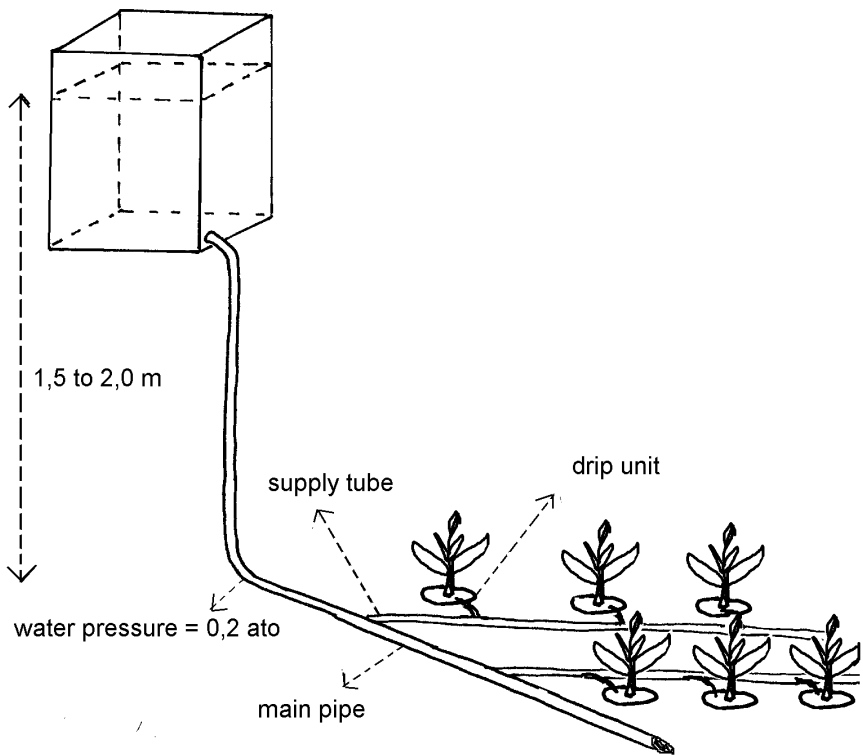


Figure 23: Drip irrigation system (schematic)

6.4 Disease control

Worth mentioning yet again is that to obtain high quality crops in greenhouses you need to pay a lot of attention on to the quality of the material you use. The prevention of disease, in particular, deserves extra attention. This is why it is advisable to disinfect footwear at the entrance of the greenhouse. It would thus be handy to place a tray on the ground containing a mat kept soaked in liquid disinfectant.

Furthermore, if the crop is planted in rows in the greenhouse length-wise, some of the work to do with disease control can be carried out more easily. Spraying equipment can be transported on a trolley, spraying as it is pulled along the path.

Any heating pipes present can serve as rails (see also Figure 21). We can control diseases and pests using biological agents far more effectively inside the enclosed space of greenhouses than in open fields. Parasites from harmful insects or parasitic fungi can be introduced to fight against harmful plant fungi (biological control). Greenhouse crops can therefore be considered to be environment-friendlier than outdoor crops.

Finally, we can also use insecticidal gasses to protect the crop in the greenhouse provided that the greenhouse can be closed well and the weather is calm. Take extra caution with regard to the hazards to humans and animals!

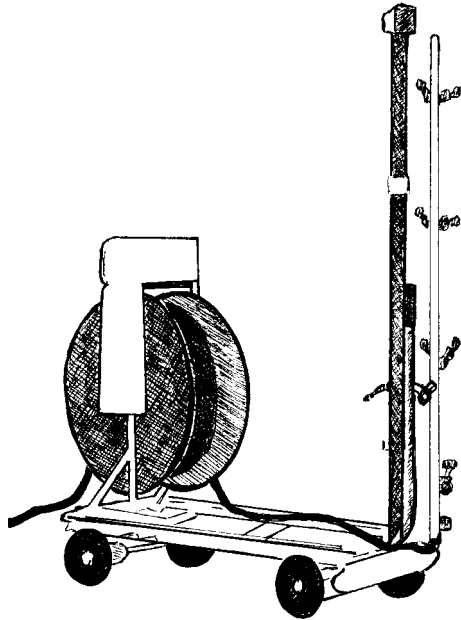


Figure 24: Trolley for transporting spraying equipment. Source: Royal Brinkman NL

When propagating young plants it is extremely important to be aware of infections caused by carriers of (virus) diseases, such as aphids. Protections of the nursery areas with insect netting works well and there are several types for this purpose on the market.

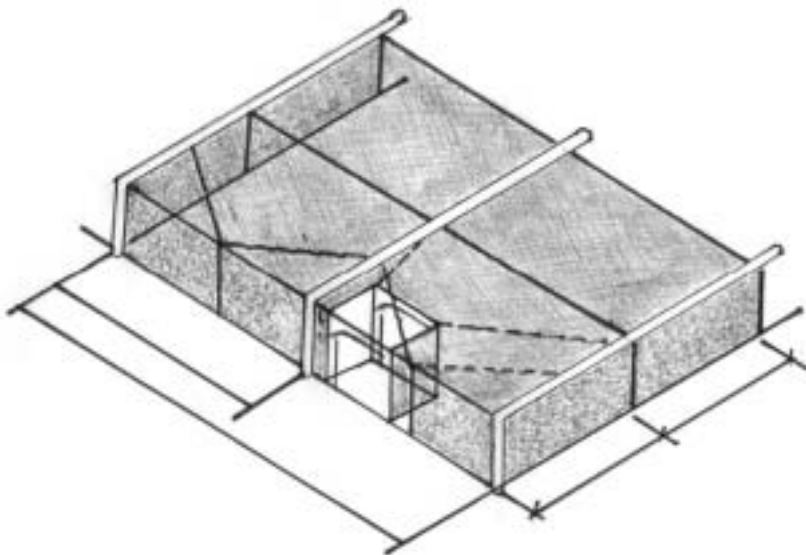


Figure 25: Nursery crops in small insect proof greenhouse with entry sluice (Rovero)

6.5 Spaces for storage and preservation

You need space for the safe storage of materials. In particular, plant protection agents need to be stored away so that they cannot fall into the wrong hands. Fertilisers and bedding soil also need to be well protected against rain and leaching. Also needing protection and just as important are your tools and machinery.

To maintain the quality of the harvested products one must ensure that they are protected from the sun and wind so that they do not dry out. The simplest way is in a space where fan and pad cooling can be applied (see also Section 5.2 on cooling). For those who can afford it there are also cold rooms for this purpose. Preservation of the quality of your product can automatically be translated into a better price, for which you have after all already incurred the necessary expenses.

6.6 Necessary instruments and tools

Instrument for meteorology (rain):

- A standard rain gauge for daily readings, consisting of upper part with limit ring, lower part with collecting jar and measuring vessel sufficient for up to 10 mm rainfall.

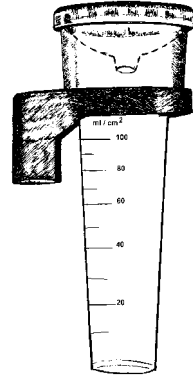


Figure 26: Rain gauge

Instruments for meteorology (temperature):

- Thermometers are available for measuring the temperature. However, a maximum - minimum thermometer (see Figure 27) would be very useful to get a better insight into the variation in the temperature during the course of an entire day. You can then read off the maximum and minimum temperatures reached during the preceding period and then adjust it back to zero.

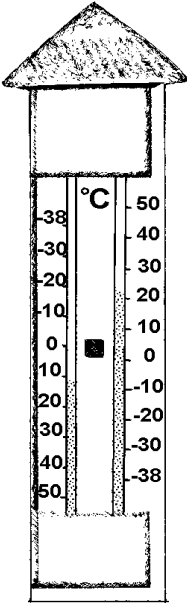


Figure 27: Maximum-minimum thermometer

- The air humidity can be measured using a wet-dry bulb thermometer. This instrument consists of two thermometers one of which has a wet sock around its bulb. This must be kept moistened with clean water daily. The wet bulb is cooled by evaporation proportional to the drop in air humidity. You can read off the air humidity (RH) using a table.
- A very handy and somewhat more expensive apparatus is the thermohygrograph. This continually records the temperature and the air humidity of an entire week on special graph strips. This apparatus needs to be checked (calibrated) regularly (annually) for accurate readings.

The measuring equipment must be set up in such a way to avoid direct sun shining on it. The best solution is to put it in a ventilated box. This is a box with slatted sides that slope in such a way as to prevent the sunlight from entering it. It is placed at a height of about 1.50 metres from the ground.

Instruments for soil quality survey:

- Edelman soil auger. A simple one-piece 7-centimetre diameter Edelman soil auger. This is used to take soil samples up to a depth of one metre. It is also used to measure the depth of the groundwater, which can influence the rooting of the plants. There are different types to suit the diversity of soil types.
- Soil sample hand bore. This is handy for sampling soil up to half a metre in depth.

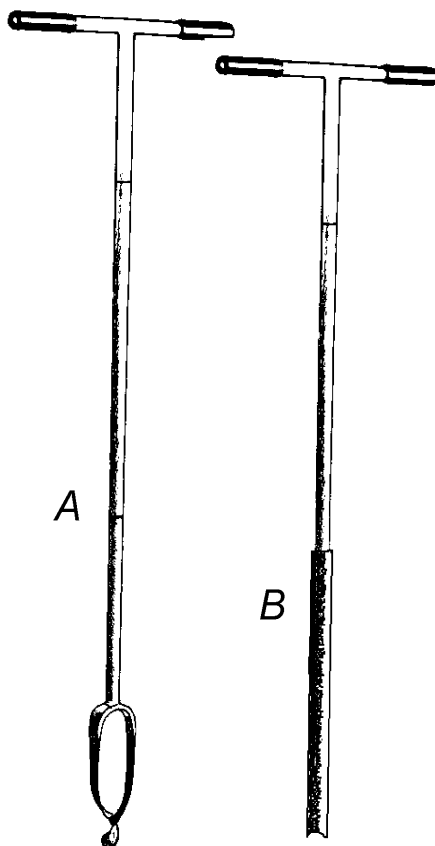


Figure 28: Edelman soil auger (A) and soil sample hand bore for 0.5 meter depth (B)

Measuring air humidity:

- Thermo-hygrograph; provided with a bimetallic temperature sensor and hair harp as humidity sensor. The measuring range is 0 – 100 % relative humidity and standard temperature range between – 20 to + 40 °Celsius. The instrument records continually the temperature and humidity of an entire week on special graph strips. To secure accurate reading it must regularly be checked.

Surveying instruments:

- Hand level. Simple instrument for rapid determination of elevation and depression angles. Particularly suitable for preliminary surveys cross sectioning gradient and slope determination.

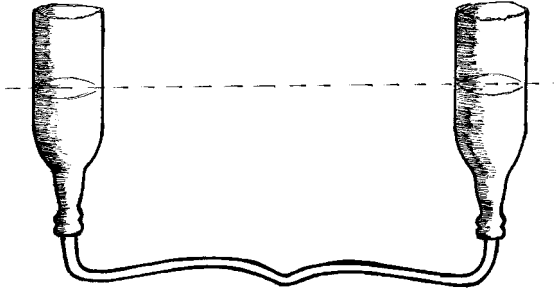


Figure 29: Hand level made of bottomless plastic bottles

Agricultural diagnostics equipment

- Digital pH-meter for measuring the degree of acidity in water or in a soil extract. Crops in general grow best in an environment with pH values varying between 6 and 7. The measuring range varies between 0 and 14.
- A digital EC meter and accompanying electrode to measure the degree of harmful salts in a soil solution or in irrigation water. This instrument measures salt concentrations quickly and accurately. There are three measuring ranges; 0.1 to 1.0; 1.0 to 10.0; 10.0 to 20.0 $\mu\text{S}/\text{cm}$ (micro Siemens per cm).

7 Crop selection, care, labour and yield

7.1 Introduction

This chapter contains the more general guidelines for choosing the crops that can be grown in the different types of greenhouses and under plastic film. It also deals with the most important aspects pertaining to the cultivation of the different crops. We assume that someone choosing to grow greenhouse crops would already have much experience with growing vegetables. New crops can sometimes appear on the market thanks to greenhouse cultivation.

7.2 Crops for different types of greenhouses

Examples of suitable crops that can be grown in the types of greenhouses described in Chapter 3 are given below. We also need to distinguish between low-growing and taller crops, as the latter will always need more space.

Crops under plastic sheets

Only low-growing crops can be raised purely and simply under plastic sheets and not those that shoot up high. Examples are: lettuce and strawberries that are kept covered in areas that are cold at night, for as long as it is deemed necessary during the cold weather.

Next comes asparagus. The plastic film retains the warmth and cooling is slowed down, which encourages early sprouting of the shoots. Black-white plastic is usually used to enable continual reaping of harvestable shoots like white asparagus. The plastic sheets are removed momentarily during harvesting. When the period of harvesting the shoots is over, the stalks are allowed to grow freely for photosynthesis to build up sufficient reserves in their root system from which a robust plant can develop.

Crops in low constructions and low tunnels

Examples: lettuce, turnip, radish, beetroot, Chinese cabbage and pak-soy. These soon have plenty of room. Thanks to the space between the soil and plastic in these constructions, taller plants such as strawberries, low-growing tomato varieties, sweet peppers, aubergine (egg-plant) and chillies, can also be grown here. The choice of the crop depends solely on the optimum height of the plant.

Crops for the tunnels, double- and multi-span greenhouses and tall greenhouses

Tunnels, double- and multi-span greenhouses are tall enough to be able to grow the entire assortment of vegetables. The various different African and South American highland flowers are also cultivated in greenhouses such as these.

Tall greenhouses have the advantage of a favourable heat distribution because there is ample room inside them for good air circulation. The whole business of climate control runs much smoother here. We use these greenhouses for tall crops like tomatoes, egg plants and cucumbers. These are plants that easily reach a height of over two metres and are supported using cord tied onto horizontal overhead wires. The wires are attached to the greenhouse construction.

Crops for shade halls

Crop protection using shade halls takes place mainly in regions where there is a lot of sun and where crops are grown that need shade. In (semi-) arid regions people use these greenhouses for flower growing, among other things. In tropical areas they are suitable for growing orchids in.

7.3 Crop care

In this section is a sketch setting out a few main aspects of plant care. This Agrodok, after all, aims at providing information about different types of greenhouses and everything that is required to grow crops inside them.

Seeds, sowing and transplanting

It is vitally important that greenhouse growers – who have already invested in everything they need – also use the best quality seed that can be found on the market. Reputable plant breeders have a vested interest in producing seed for sowing that is of uniform quality and superior germination capacity. This seed is often bred in such a way that they are resistant to certain diseases or pests and usually pertains to hybrid seeds that cannot be reproduced by the grower.

The greenhouse grower will sow the seed on seed trays and after the necessary selection nursery transplant them in individual pots in which the plants will grow until they are transplanted onto their final growing space. It is essential that all of this takes place with the utmost care, because the success of the crop is very dependent on this. Therefore, the soil in which the plants are grown should not contain pathogens and should be disinfected where necessary. Great care should be taken to keep the plants free from aphids. This is why it is important to ensure that ventilation openings of the nursery areas are equipped with insect netting. Any affected plants must be removed immediately.

Soil preparation

When cultivating the soil always remember that plants need well-aired soil for easy drainage. Waterlogging must be prevented at all costs. Plants grow best in a rooting environment consisting of one-third soil, one-third air and one-third water. Preparation of the soil should not be a problem for the experienced grower.

Fertilising

When preparing the soil it would be advisable to immediately work in fertiliser of organic or inorganic origin.

Organic fertiliser is of a good quality if it contains well-decayed material so that bacteria will have little chance of nitrogen fixation, thus freeing the nitrogen for the plant's use. *Inorganic fertiliser* can be given as single or as mixed fertilisers. There are also *liquid fertilisers* on the market that can be easily mixed with the irrigation water (ferti-gation).

There are three primary elements of significance, namely, nitrogen (N), phosphorus (P) and potassium (K).

- Many fertilisers also contain added magnesium (Mg).
- Secondary elements such as sulphate (SO₄) and calcium (Ca) are also present in chemical fertiliser just like boron (B), manganese (Mn), copper (Cu), zinc (Zn) and molybdenum (Mo).

The above-mentioned elements are indicated on the packaging in percentages of weight. For example: 20-10-15-4 indicates that the fertiliser contains 20% nitrogen, 10% phosphorus, 15% potassium and 4% magnesium. The rest of the weight is made up of buffer substances including calcium and sulphate. Most of the fertilisers are available in pellets. The advantage of higher percentages is the lower transport costs.

Chemical fertilisers usually contain much sulphate and sometimes also chloride (Cl). This last-mentioned element can rapidly accumulate in greenhouse soils, reaching a high growth retardation level detrimental to the plants. This is why high demands must be placed on fertilisers for use in greenhouses. A so-called horticultural quality is used. This is a delicate issue for salt-sensitive crops grown in substrate and for pot plants.

The amount of fertiliser used is largely dependent on the fertility of the soil. In the beginning of the growth period we use little chemical fertiliser. Fruit crops like tomatoes get somewhat more potassium when they are about three weeks old until the first yield to enhance the firmness of the fruits. Later, they are given extra nitrogen when the plants are laden with heavy fruit and vegetative growth is therefore retarded.

We are unable to give you clear and unambiguous advice here. We suggest that you seek advice from test laboratories in the region or abroad (see appendix for list of advisory institutes). They can do soil and water analyses and, based on these, give you advice on appropriate fertiliser usage.

Transplanting in outdoor beds

Transplanting of the plants for the purpose of open-ground cultivation is done in ready-made planting holes. The actual planting will not be a problem for the experienced grower. Each crop has its own criteria, which will not be described here.

Daily checking

Climate control of the greenhouse calls for daily attention. This has been dealt with extensively in previous other chapters. The water supply of the crops is also largely dependent on the changes in the weather; the amount of irrigation water also depends on the development stage of the crop. As a rule, sprinkling should not be done too late to avoid the plants remaining wet at night.

Extremely important is to check the crops very regularly to prevent diseases and pests from affecting the plants. As long as the damage is local, disease control can be restricted to these spots only. This limits the costs, labour and impact on the environment. The toxicity of the agents used can cause health problems for the labourer. Be aware of this and make use of protective clothing and equipment.

Crop husbandry: support and weeding

Both low-growing as well as tall crops need to be tended well. Weed control is necessary to avoid competition for roots and light as much as possible. Taller plants such as tomatoes, egg plants, melons and cucumbers must be supported well using cord or string.

The old leaves on these plants should also be removed preferably by cutting them off close to the stem. Leave the green leaves on the plants, especially in the early stages of growth. Less leaves means less photosynthesis. When plants have more space between them the leaves remain green longer and then can also be left on the plant longer.

When growing tomatoes remember to pinch out shoots (axillary buds), which needs to be done weekly during the tender growing phase. This is done at the same time when the plant tops are twisted around the supports. Side shoots that are too big should be cut off with a sharp knife.

Harvesting, quality and selection, packaging and transport

Harvesting should be done with care and caution to ensure that the quality is safeguarded as much as possible. A clean and uniform product of good quality will be rewarded with the highest price. Do not let the harvested product lie in the sun for long and store it in a cool place if at all possible, for instance in a warehouse.

The labour of harvesting of crops cultivated in rows could be lightened by using trolleys like for spraying (see 0) to support a container.

Packaging helps to safeguard the quality of the product. Naturally you will need special containers, carton or plastic boxes, particularly for the products that need to be transported over longer distances. The transport should not be allowed to have an adverse effect on the quality.

7.4 Labour intensiveness

You need to take into account that cultivating vegetables is a very labour-intensive business, which can require 800 manpower days per hectare per crop season, and this is not an exaggeration. Some crops need even more labour depending on how long they remain in the greenhouse. The annual figures are higher in some holdings that cultivate more than one crop per year.

Below is an overview of the necessary steps for the production of a crop.

In the nursery:

- Preparation of the seedbeds
- The sowing
- Preparation of the potting soil
- Transplanting into paper pots or other kinds of containers
- Moving to nursery tables/nursery beds
- Maintenance and check of sanitation
- Control of diseases/pests

In the greenhouses:

- Soil preparation
- Fertilisation
- Levelling
- Planting of seedlings
- Irrigation, and topdressing
- Crop maintenance, care
- Control of diseases and pests
- Harvesting, selection, packaging, transport

There can be enormous differences in labour intensiveness between the different crops. The size of the business determines whether family labour can cope with all of the work. Frequently, peaks in the demand for labour necessitate taking on help from the outside. When setting up a big holding extra labour needs to be taken into account right from the start. The greenhouse grower will need to make use of existing crop budgets in the region for this purpose.

7.5 Financial turnover

Exploitation of greenhouses, buildings and machinery also involves taking into account that one's net profits must also cover all debits, interest on borrowed capital, labour costs, costs of production requirements and rent and tenancy. It is obvious, therefore, to start with simple greenhouses that need little investment and to choose crops with a high market value and a good performance.

It is of utmost importance that the bookkeeping clearly shows the fixed liabilities and that you put away enough money to cover the necessary debits. Having done this, when everything has been written off, there will be sufficient capital available for new investments.

Whenever growers decide to invest in improvements of their production systems they also need to make sure that their income will also grow adequately. Care needs to be taken that the investment also means improvement of the market value of the products.

The golden rule is that the greenhouse grower starts on a small scale, gains experience and only then considers expanding the business and investing more.

This is the thread that has been followed throughout the history of greenhouse growing. Experience has proved that small businesses grow into big ones. Alas, there are also examples of holdings that have been too big at the set up and have quickly gone bankrupt because of mistaken notions of income and costs. And, because cultivating in greenhouses always means extra investments, the greenhouse grower will always need to thoroughly and carefully weigh up the pros and cons beforehand.

Appendix: Climate tables

Table 5: Average monthly rainfall in millimetres from a few global weather stations

Month	Lod Airport Israel	Quito Ecuador	New Delhi India	Nairobi Kenya	Chiang- may Thailand	Band- ung Indone- sia
Jan	144	114	22	88	8	137
Feb	113	127	19	70	7	180
Mar	65	150	13	96	16	248
Apr	21	171	7	155	45	225
May	4	122	13	189	146	160
Jun	0	47	67	29	137	59
Jul	0	20	202	17	169	30
Aug	0	23	197	20	222	25
Sep	0	77	123	34	270	78
Oct	26	125	18	64	143	174
Nov	69	108	2	189	40	222
Dec	162	101	9	115	14	203
Total	604	1185	692	1066	1217	1741

(Source: FAO, 1992 AMDASS, Agro Meteorological Data System. FAT Agroclimatic databases FAO Rome)

The rainfall figures in dry as well as wet regions from the six weather stations above show widely divergent values. Lod Airport has four months of absolutely dry weather with little rain during the remainder of the year. It is extremely important to be sparing with water here. In New Delhi, the situation is comparable. In Chiangmay and Bandung, on the other hand, people would need to be more concerned about too much water. The rainfall varies from year to year. Peaks, either upwards or downwards, could lead to problems. Therefore, we should

pay extra attention to drainage of excess water during extremely wet years. And, during extremely dry years, the storage of extra water for irrigation is essential. Data from the extreme years in Chiangmay serve as an illustration (Table 6).

Table 6: Extreme maximum, average and extreme minimum rainfall in millimetres in Chiangmay

Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
95	88	84	139	441	347	405	526	592	345	160	85	3407
8	7	16	45	146	137	169	222	270	143	40	14	1217
0	0	0	2	7	32	54	75	36	7	0	0	231

(Source: UN Atlas of the lower Mekong-Basin, 1968)

The above table show the extremes in rainfall years. During extremely wet years pay extra attention to drainage of excess water. Storage of irrigation water is essential for extremely dry years.

Table 7: Average maximum and minimum temperatures in °C van a few places

Places	Lod Airport		Quito		New Delhi		Nairobi		Bandung	
	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
Jan	18	8	22	8	21	7	25	11	29	17
Feb	19	7	22	8	24	10	26	11	29	17
Mar	20	8	22	8	30	15	26	13	30	17
Apr	24	10	21	8	36	21	24	14	30	17
May	29	14	21	8	41	27	23	13	30	16
Jun	30	17	22	7	40	29	22	11	30	15
Jul	32	19	22	7	35	27	21	9	29	14
Aug	32	20	23	7	34	26	22	10	30	14
Sep	31	19	23	7	34	25	24	10	30	15
Oct	29	16	22	8	33	19	25	12	31	16
Nov	26	13	22	7	29	12	23	13	30	16
Dec	20	9	23	8	23	8	23	13	31	17

In most of the subtropical countries, like the coastal strip of Israel (Lod Airport), a few crops could do with some additional heating during the winter. In tropical highlands, such as in Quito, additional heating at night all year round is advisable, possibly also in the highlands of Kenya. In New Delhi, on the contrary, the temperatures during the summer are very high. Then, the use of screens and cooling systems – if financially feasible – become a necessity. In Bandung (semi-wet tropics) there are restrictions only for crops requiring a fairly low temperature.

Table 8: Average sunshine hours in hours per day in a few global weather stations

Place	Lod Airport Israel 32°NBr	Quito Ecuador 0.09°ZBr	New Delhi India 28.35°NBr	Nairobi Kenya 1.18°ZBr	Bandung Indonesia 6.53°ZBr
Jan	5.88	5.76	7.59	8.80	6.42
Feb	6.81	5.52	8.66	9.27	6.48
Mar	7.43	4.08	8.15	8.64	6.74
Apr	8.95	4.44	9.25	7.18	6.88
May	10.79	4.56	9.53	5.85	7.25
Jun	11.97	5.16	7.45	5.85	7.56
Jul	11.81	5.64	6.40	4.30	8.51
Aug	11.31	7.32	6.37	4.19	8.72
Sep	9.51	5.64	7.54	5.76	8.14
Oct	8.93	5.64	8.81	7.10	7.19
Nov	7.65	6.00	9.19	6.87	6.77
Dec	5.95	5.52	8.16	7.96	6.44

In Lod Airport the longer days in the dry summers have a clearly positive effect on the number of hours of sunshine, while in New Delhi the number of sun hours are somewhat limited by the clouds during the summer monsoon. In the three other stations lying close to the equator, the differences are mainly due to the seasonal pattern of clouds and rainfall.

Table 9: Average air humidity in % RH of a few places across the globe

Month Place	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Lod Airport	69	73	74	72	66	68	68	70	68	64	64	71
Quito	70	71	71	74	73	67	61	57	62	69	69	69
New Delhi	55	46	36	25	25	38	64	70	61	46	39	49
Nairobi	69	65	68	73	77	73	76	72	69	64	74	74
Bandung	75	75	76	78	78	77	75	71	68	72	76	73

The average air humidity values only give a global indication. As a rule, the RH is highest early in the morning and lowest at midday. These are the critical moments for controlling of the climate in the greenhouse. In the table only New Delhi springs out because of its extremely low air humidity during a few summer months. There, in the middle of the day, there are bound to be climate problems that make active cooling essential for successful cultivation. This applies especially to semi-desert regions in the subtropics.

Table 10: Potential evaporation (Eo) in millimetres per day from a few global weather stations

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Lod Airport	1.6	2.2	3.2	4.6	6.6	7.4	7.4	6.8	5.2	3.7	2.5	1.6
Quito	3.9	4.1	3.9	3.8	3.7	3.7	4.0	4.7	4.4	4.2	4.0	3.8
New Delhi	2.4	3.5	5.7	7.7	9.2	8.5	6.8	6.1	5.7	4.6	3.2	2.3
Nairobi	5.4	6.0	5.9	5.1	4.3	4.0	3.5	3.9	4.7	5.3	4.8	4.9
Bandung	5.2	5.3	5.4	5.1	4.8	4.6	4.9	5.5	5.9	5.7	5.3	5.3

The combination of much sun, high temperatures, a low RH and possibly a lot of wind determines the striking high evaporation during the summer months in New Delhi. Much lower temperatures and a rather high RH accompany the great deal of sunshine in Lod Airport, so that the evaporation is less extreme here.

Table 11: Cooling in °C when the effectiveness of the fan and pad cooling system is 80 %

RH/Outside temp in °C	10%	20%	30%	40%	50%	60%	70%	80%	90%
10°	6.7	5.9	5.1	4.3	3.5	2.8	2.1	1.4	0.6
15°	8.2	7.2	6.2	5.2	4.2	3.3	2.4	1.6	0.8
20°	9.8	8.5	7.3	6.1	5.0	3.8	2.8	1.8	0.9
25°	11.5	9.8	8.5	7.0	5.6	4.4	3.2	2.1	1.0
30°	13.3	11.4	9.5	7.8	6.3	4.9	3.5	2.3	1.1
35°	15.1	12.8	10.6	8.7	7.0	5.4	3.9	2.5	1.2
40°	17.0	14.2	11.8	9.7	7.8	5.9	4.2	2.7	1.3
45°	18.9	15.7	13.0	10.5	8.3	6.3	4.6	2.9	1.4

It is obvious that at a temperature of even above 40° C good growth conditions could still be created as long as the air humidity is low, for instance between 10 and 20 %. Cooling, however, is hardly feasible under circumstances of high humidity. Fan and pad cooling, therefore, is not an option in the semi-humid and humid tropics.

Further reading

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Vegetable growing in greenhouses in arid areas in the subtropics

Part 1: Soil and water; Part 2: Crops. Min of Agric. and Fishery, Stiboka 1987-88

Useful addresses



PTC+ is an international training institute, which focuses on all the links in the production chain on plant and animal commodities, (agricultural) technology, (food) technology and natural areas.

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Rovero Systems B.V.

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Tel.: +31 (0)162 574544; Fax: +31 (0)162 574500;

info@rovero.nl; www.rovero.nl

Tunnels, Multi Rovero greenhouses, Rol-Air greenhouses, Clima Halls, Agrocover

Haygrove Tunnels

Redbank, Little Marcle Road, HR8 2JL Ledbury, Heref.shire , U.K

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hilary.ramsay@haygrove.co.uk; www.haygrove.com

Field-scale tunnels

Yamco-Yadpaz

Greenhouses, 65 Yig'al Alloon st. Tel Aviv 67433 Israël

Tel: 972-3-5622557, Fax: 972-3-5622558

yamco@netvision.net.il ; yamko.co.il

Greenhouses, nethouses, multished

Klerk's / Hyplast Nv

St Lenaartseweg 26, B-2320 Hoogstraten Belgium

Tel: +32 (0)331 43740 Fax: +32 (0)331 42372; info@hyplast.be

Various films for greenhouse cover

Polysak Plastic Industries Ltd.

Kibbutz Nir-Yitzhak, IL85455 M.P. Hanegev Israël

Tel: +972 8 9989720/1, Fax: +972 8 9989710

sales@polysack.com; www.polysack.com

Shade netting, wind protection

Royal Brinkman International Bv

PO Box 303, 2690 AH 's Gravenzande, The Netherlands

Tel: +31 174 446100, Fax: +31 174 446151

export@brinkman.nl ; www.brinkman.nl

All sorts of greenhouse equipment

Ludvig Svensson Bv,

Marconiweg 2 3235 LV Hellevoetsluis. The Netherlands

Tel: +31 181 392666, Fax: +31 181 392662

info@svensson.nl ; www.ludvigsvensson.com

Climate control screens, anti insect netting, groundcover

Holland Heater De Lier Bv,

Leehove 62 2678 MC De Lier, the Netherlands

Tel: +31 (0)174 516741, Fax: +31 (0)174 518021;

info@hollandheater.nl

Hot air blowes in gas- or oil-fired versions, greenhouse ventilators

Revaho Bv Handelonderneming

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www.revaho.nl

Irrigation equipment

Eijkelkamp Agrisearch Equipment

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Tel: +31 313 631941, Fax: +31 313 632167

eijkelkamp@eijkelkamp.com.nl www.diva.nl/eijkelkamp

Agricultural laboratory and field investigation instruments

Nieuwkoop Bv

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Tel: +31 297 325836, Fax: +31 297 323167, info@nieuwkoopbv.nl ;

www.nieuwkoop.nl

Measuring instruments for climate control, soilfertility and irrigation management

Koppert Bv. Biological Systems

Veilingweg 17, PO Box 155, 2650 AD Berkel en Rodenrijs, The Netherlands, Tel: +31 10 5148444, Fax: +31 10 5115203

A.Taal@koppert.nl ; www.koppert.nl

Biological products for pest- and diseasecontrol

Internet:

For those who have access to the Internet, three major websites will lead you to a wealth of information.

www.cityfarmer.org

Canada's office of urban agriculture

www.ruaf.org

ETC Centre for Sustainable Agriculture, Netherlands

www.echonet.org/tropicalag/aztext

ECHO (Educational Concerns for Hunger Organization), Florida, USA. This site, with the beautiful name "From Amaranth to Zai Holes", has been growing since 1996 and gathering a wide range of practical ideas for those who work for communities living under difficult conditions in the tropics and subtropics. It shows there are no simple answers, but there are many possibilities and potential methods and technologies.

Radio:

Developing Countries Farm Radio Network (DCFRN)

Presents itself at www.farmradio.org

E-mail info@farmradio.org

With radio being the primary method of communication, DCFRN assists farming families in about 100 countries in the Caribbean, Southern and Central America, Africa, Asia and Pacific, with learning about simple proven ways to increase food supplies and nutrition and health. In English and in French.

Glossary

Crop-water-requirement (Etcrop): refers to the water need of the crop, which includes transpiration of the crop as well as direct evaporation from the soil.

EC = Electrical conductivity: measure of salt content in the extracted soil water when the soil is saturated with water expressed in millimhos per cm.

Ece-meter: digital meter (also in pocket size) to measure the salt concentration in water or in a soil-water extract.

Eo: Potential evaporation: the evaporation from a land surface covered with vegetation and with sufficient soil water.

Evaporation: is used denoting the sum of water physically evaporating from the soil.

Fertigation: Artificial fertiliser application in a closed irrigation system. Pesticides and fungicides can also be applied in this way.

IR-Transmission: Penetrability of heat radiation through plastic films.

Multi-span greenhouses: Greenhouses with more than two attached covers (tunnels). **Photoperiodicity:** This is the influence of the day length on the behaviour of the plant affecting the blossom. There is a difference between plants that flower under shorter or longer daytime conditions, which is identifiable in plants in the tropics and the temperate zone

Nursery transplant: Moving individual plants from seedbeds to pots or nursery beds to enhance the quality of the planting material

PH or Soil reaction: the degree of activity of a moist soil indicated by the hydrogen-ion concentration.

PH-meter: digital meter (in pocket size) to measure the acidity in moist soil. The most favourable levels are in the range between 6 and 7.

Photoperiodicity: many crop plants react for their flowering period on the length of the day. The so-called short day plants start flowering when the daylength is 12 hours (in the tropics). When planted in the temperate zone, they continue to vegetative growth only. The long-day plants do flower only when days are long days ($= > 15 - 18$ hours).

Plant or crop husbandry: Tending/caring for the crop from sowing through to the harvest.

Protected cultivation: Growing of crops protected from climatic influences.

RH = Relative Humidity: actual amount of water vapour at a given temperature in relation to the maximum amount the air can hold at that temperature – percent.

Solar radiation: radiation from the sun's rays

Transpiration: is the sum of water physiologically evaporated or transpired by the plant.

Vacuum-effect: strong stream of air over the greenhouse cover induce lower air pressure within the greenhouse

Ventilation box: Box protecting against sunlight allowing for free airflow

Wilting point: of plants in a soil is reached when the suction force of plants cannot overcome tension by which ground water is tied by the soil. At this point plants start to wilt.