The African Greenhouse

A toolbox

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Report GTB-1360

WAGENINGEN UR
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Referaat
Er is behoefte aan beslissingsondersteuning bij het ontwerpen van kasproductiesystemen in verschillende klimaatzones en locaties in Afrika: de 'Toolbox Adaptive Greenhouse Systems for Africa'. Selectie van een beperkt aantal klimaatzones die karakteristiek zijn voor Afrika beperkt de variatie in het aantal ontwerpen dat moet worden geëvalueerd en geeft een meer effectieve benadering voor de Nederlandse toeleverende industrie. De toolbox zal resulteren in een aantal kasproductiesystemen die voor een bepaalde locatie het meest geschikt zijn, waarbij verschillende elementen worden gewogen: kastype, kasinstallatie, klimaat, productie en economische levensvatbaarheid. De toolbox zal de 'adaptive greenhouse approach' volgen, waarin modellen voor kas, gewas en financiën worden gecombineerd. Dit rapport levert een basis voor de toolbox. Het geeft een overzicht van Afrikaanse klimaten, gevolgd door opties voor kasontwerp die in de context van een aantal productiesystemen geplaatst. De verwachte toekomstige ontwikkelingen en transities van de huidige naar mogelijke toekomstige situaties worden kort beschreven. Anticiperen op verwachte toekomstige ontwikkelingen maakt analyse van een bepaald bedrijfstype, de voorwaarden voor ontwikkeling en de opties voor Nederlandse betrokkenheid mogelijk.

Abstract
There is demand for a decision support tool to design greenhouse production systems in various climate zones and locations in Africa: the 'Toolbox Adaptive Greenhouse Systems for Africa'. Selection of a limited number of climate zones that are representative for Africa limits the variation in designs to be evaluated and makes the approach more effective for the Netherlands supply industry. The toolbox will result in a number of greenhouse cultivation systems that are most suitable for a given location, weighing perspectives such as greenhouse type, greenhouse installation, climate, production and economic viability. The toolkit will follow the 'adaptive greenhouse approach' in which models for greenhouse, crop and finances are combined. This report provides a basis for the toolbox. An overview of African climates is given, followed by options for greenhouse design which are placed in the context of a number of production systems. The expected future developments and the transitions from current situations to likely future situations are briefly described. Anticipating likely future developments enables an analysis of the potential of a certain farm type, the requirements for further development, and the options for Netherlands involvement.

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Summary

There is demand for a decision support tool to design greenhouse production systems in various climate zones and locations in Africa: the 'Toolbox Adaptive Greenhouse Systems for Africa'. Selection of a limited number of climate zones that are representative for Africa limits the variation in designs to be evaluated and makes the approach more effective for the Netherlands supply industry. Such a toolbox will require the investment of several public and private partners. The toolbox will result in a number of greenhouse cultivation systems that are most suitable for a given location, weighing perspectives such as greenhouse type, greenhouse installation, climate, production and economic viability. The toolkit will follow the 'adaptive greenhouse approach' in which models for greenhouse, crop and finances are combined.

This report provides a basis for the toolbox. An overview of African climates is given, followed by options for greenhouse design: greenhouse constructions, greenhouse covers, climate systems, screens, substrates, water management, energy, fertigation systems, crop protection, and post-harvest issues. These are placed in the context of a number of production systems, viz., subsistence farming, small to medium farms, medium to large farms, farms growing speciality crops, urban and metropolitan horticulture, and agroparks. The expected future developments and the transitions from current situations to likely future situations are briefly described. Anticipating likely future developments enables an analysis of the potential of a certain farm type, the requirements for further development, and the options for Netherlands involvement. The potential of the toolbox is illustrated with examples from Algeria, Indonesia, Malaysia, Taiwan and Abu Dhabi.

Samenvatting

Er is behoefte aan beslissingsondersteuning bij het ontwerpen van kasproductiesystemen in verschillende klimaatzones en locaties in Afrika: de 'Toolbox Adaptive Greenhouse Systems for Africa'. Selectie van een aantal klimaatzones die karakteristiek zijn voor Afrika beperkt de variatie in het aantal ontwerpen dat moet worden geëvalueerd en geeft een meer effectieve benadering voor de Nederlandse toeleverende industrie. Zo'n toolbox kan worden gerealiseerd met behulp van verschillende publieke en private partners. De toolbox zal resulteren in een aantal kasproductiesystemen die voor een bepaalde locatie het meest geschikt zijn, waarbij verschillende elementen worden gewogen: kastype, kasinstallatie, klimaat, productie en economische levensvatbaarheid. De toolbox zal de 'adaptive greenhouse approach' volgen, waarin modellen voor kas, gewas en financiën worden gecombineerd.

Dit rapport levert een basis voor de toolbox. Het geeft een overzicht van Afrikaanse klimaten, gevolgd door opties voor kasontwerp: kasconstructies, kasdekken, klimaatsystemen, schermen, energie, watermanagement, substraten, fertigatiesystemen, gewasbescherming, en post-harvest. Deze worden in de context van een aantal productiesystemen geplaatst, namelijk subsistence farming, kleine tot middelgrote bedrijven, middelgrote tot grote bedrijven, bedrijven die speciale gewassen telen, stadtuinbouw en metropolitane tuinbouw, en agroparken. De verwachte toekomstige ontwikkelingen en transities van de huidige naar mogelijke toekomstige situaties worden kort beschreven. Anticiperen op verwachte toekomstige ontwikkelingen maakt analyse van een bepaald bedrijfstype, de voorwaarden voor ontwikkeling en de opties voor Nederlandse betrokkenheid mogelijk. Het potentieel van de toolbox wordt geïllustreerd met voorbeelden uit Algerije, Indonesië, Maleisië, Taiwan en Abu Dhabi.

1 Introduction

The demand for protected horticultural productions systems will increase over the coming years in Africa. Climate change, urbanization and a more professional production are underlying processes. Most greenhouse solutions offered in Africa by universities and companies are at the low or mid-tech level, whereas The Netherlands is a global player in greenhouse horticulture and should therefore play a leading role in the development of 'The African Greenhouse'. There does not exist one single design for a greenhouse production system in Africa. The specifications depend on the local climate, socio-economic conditions and available inputs. This calls for the development of a decision support tool to design greenhouse production systems in various climate zones and locations in Africa: the 'Toolbox Adaptive Greenhouse Systems for Africa'. Selection of a limited number of climate zones that are representative for Africa limits the variation in designs to be evaluated and makes the approach more effective for the Netherlands supply industry.

The toolbox will be developed to be used by Netherlands suppliers and African investors, and can ultimately provide the following information:

- Climate details for various locations in Africa.
- Greenhouse climate details for a number of greenhouse designs for various locations in Africa.
- Potential crop production per greenhouse design per location in Africa.
- Costs per greenhouse design, profits per crop, options to vary costs and profits, pay-back period, and cash flow. This enables economic comparison of the various designs.
- Required knowledge level for management of the crop and greenhouse, and required training and support.

Development of a comprehensive decision support tool requires a investments of several partners and donors. In such a partnership, Wageningen UR Greenhouse Horticulture has available:

- Validated climate models that dynamically (e.g. hourly) forecast the greenhouse climate on the basis of outdoor climate and greenhouse design.
- Crop growth models that can forecast production and quality for the major horticultural crops on the basis of greenhouse climate and crop management information.
- Economic models that can compute the pay-back period of investments in greenhouse systems or parts, dependent on investments, costs and profits.
- A systems engineering methodology to design greenhouse systems, taking qualitatively into account climate conditions, socio-economic circumstances, required functions of the greenhouse, possible technical solutions, and opinions of an expert panel.
- Knowledge, expertise and experience in designing greenhouses and production systems, crop management, water and nutrient management, climate management and pest and disease management.

The envisaged toolbox works as follows:

- Locations that are of interest for Netherlands suppliers are selected.
- The outdoor climate characteristics are gathered: temperature, relative air humidity, radiation, wind speed and direction, precipitation. These characteristics are presented in the form of graphics and tables.
- Available greenhouse and cultivation systems are described and used as starting point and/or reference.
- Development of a 'morphological chart' in which different functions and possible technical solutions are specified. Qualitative principles for greenhouse and cultivation systems for various climate zones are specified.
- An expert panel with representatives from disciplines such as greenhouse construction, greenhouse installations, breeding and seed supply, growth advisors and researchers selects, using the 'morphological chart' and the 'qualitative principles', a greenhouse and cultivation system that is considered most suitable for a given location.
- The various selected greenhouse types are analysed with the greenhouse climate model, resulting in time sequences of temperature, relative air humidity and radiation.
- The potential crop production is for each greenhouse type and location, computed with a suitable crop growth model.
- Various substrates (e.g., soil, slab) and systems of water collection can be considered. Optionally, the configuration of ventilation, cooling and/or heating, (de-)humidification and lamp capacity is computed, as is the effect on greenhouse climate and potential crop production.

- An economic data base with investment and operational costs for various greenhouse types and elements is developed.

The pay-back period and cash flow is computed for various locations, greenhouse types, crop production levels and product quality levels.

This document has been produced to outline some details of the approach to be followed and to identify potential partner and donor stakeholders in the further development of the toolbox.

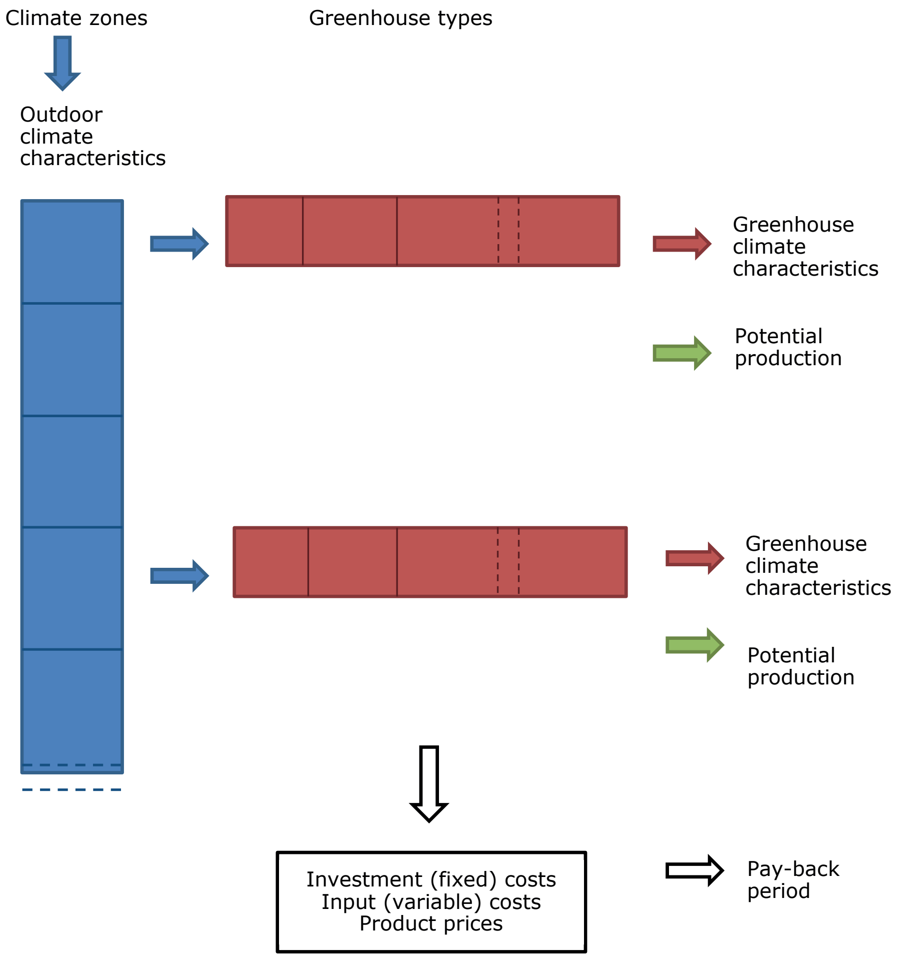

Figure 1.1 *An overview of the 'Toolbox Adaptive Greenhouse Systems for Africa'.*

2 Horticulture in Africa

2.1 Introduction

Horticulture is spread all over Africa, and vegetables are an important part of many African diets. Protected horticulture is less common, and concentrated in Northern Africa (e.g., Morocco, Algeria, Egypt), Eastern Africa (Kenya, Ethiopia, Uganda, Rwanda), South Africa, and Western Africa (Ghana). The greenhouse sector in Northern Africa mainly produces (fruit) vegetables for the European market. Export flowers form the majority of greenhouse production in Eastern Africa, and if other crops are grown, they are likely for export as well. There is an emerging greenhouse sector in Rwanda, where the SMART project has started with tomato production, and where export flower production is starting at the Gishali flower park. Greenhouses in South Africa produce both flowers and (fruit) vegetables, and greenhouses in Ghana mainly produce tomatoes and some other vegetables for the local market.

2.2 The physical environment: climate

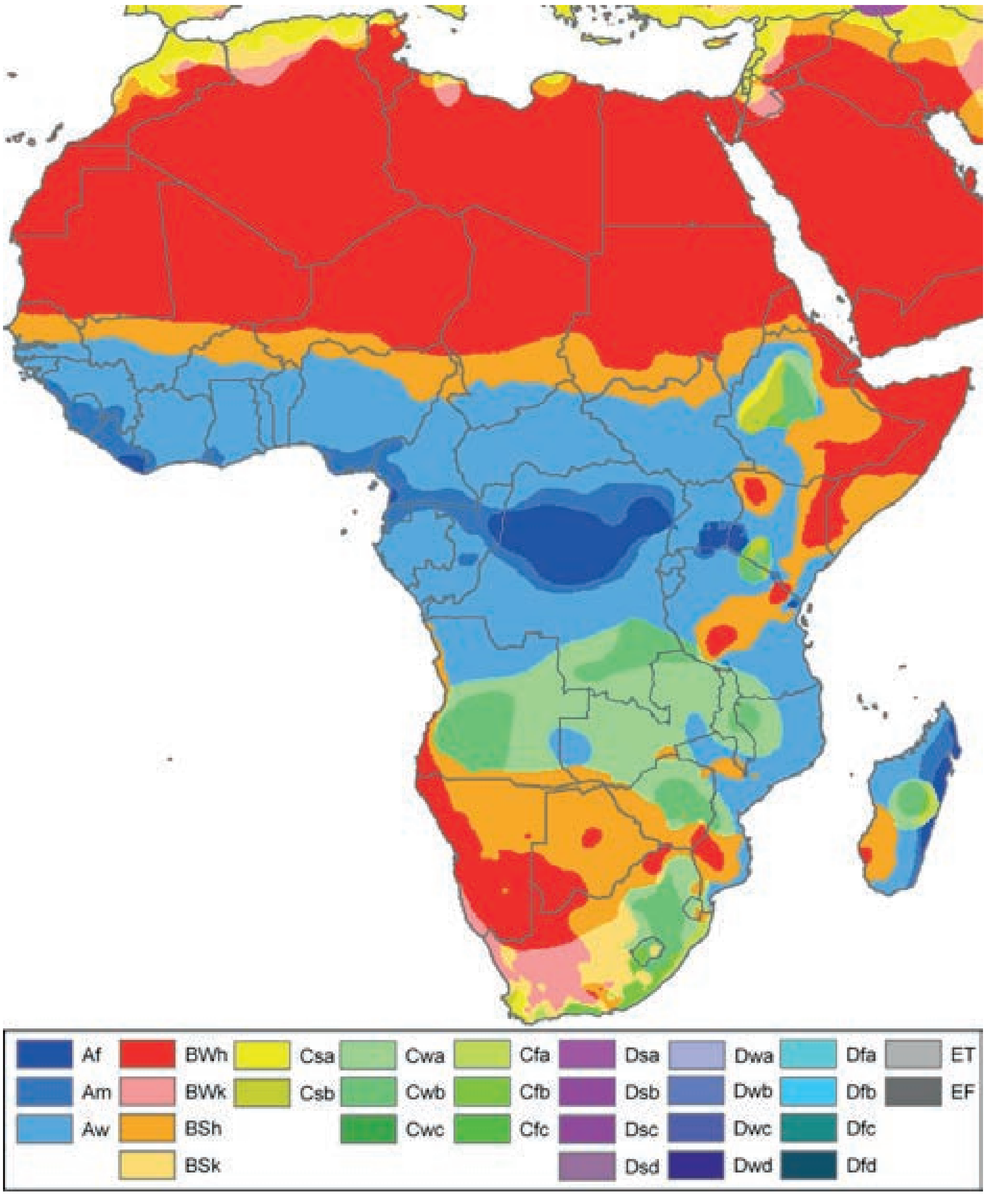

Figure 2.1 *Climate zones (Köppen) of Africa. See appendix for legend. Source: http://upload.wikimedia.org/wikipedia/commons/2/2a/Africa_Koppen_Map.png.*

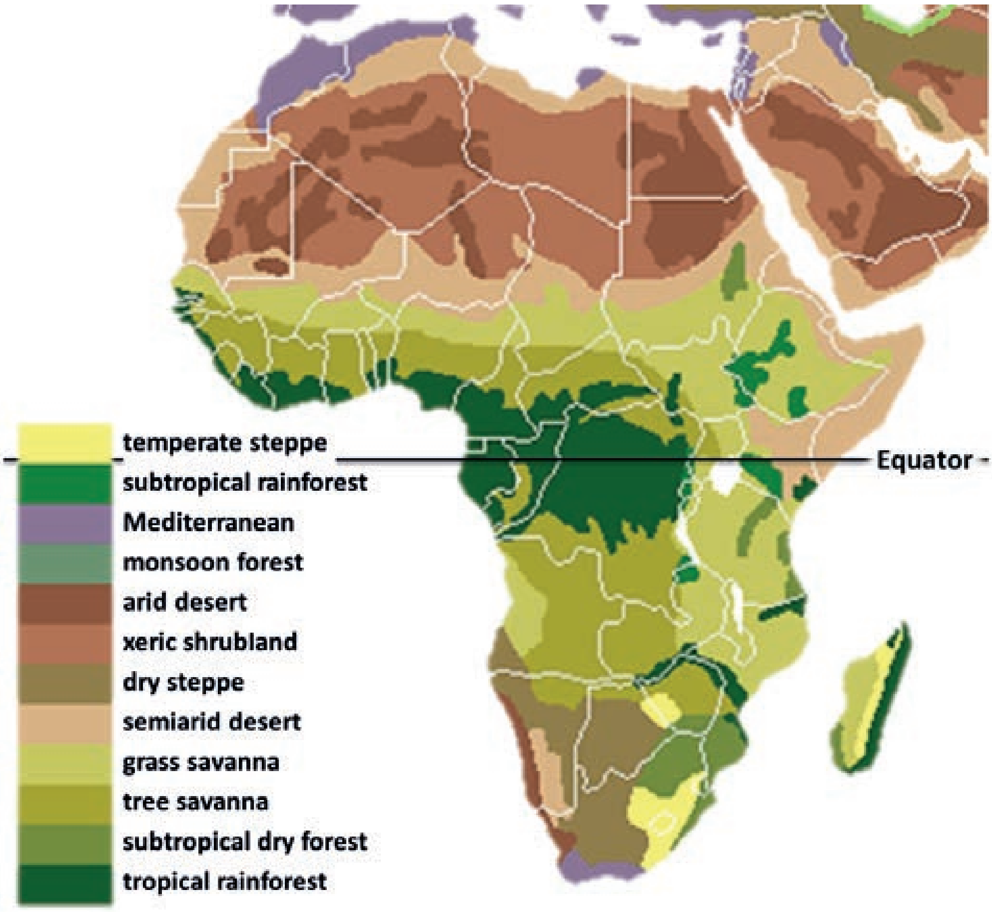

Figure 2.2 *Vegetation zones of Africa. Source: http://upload.wikimedia.org/wikipedia/commons/5/58/Vegetation_Africa.png.*

Africa is a very large continent that stretches from the southern to the northern hemisphere, is surrounded by several oceans and has a wide diversity of climates. African climates[1] and vegetation zones are given in Figure 2.1 (see appendix for the legend) and Figure 2.2, respectively. From the perspective of greenhouse cultivation, the following classification can be made:

1. The Mediterranean climate in Morocco, northern Algeria, and southern South Africa (Cape Town region) (Mediterranean on the map).
2. The desert climate in the rest of northern Africa, and Namibia and Botswana (arid desert, semiarid desert, xeric shrubland and dry steppe).
3. The highland tropical climate of eastern Africa (grass savannah and subtropical dry forest).
4. The lowland tropical climate of large parts of western, central and eastern Africa (tropical rainforest and tree savannah).
5. The semi-tropical to temperate climate of South Africa (subtropical rainforest and temperate steppe).

These climates are dealt with very briefly, and illustrated with some meteorological information.

2.2.1 Mediterranean climate

The Mediterranean climate is characterized by warm to hot, dry summers and mild to cool, wet winters. Morocco, northern Algeria and southern South Africa have this climate. The climates in Algiers, Algeria and Tanger, Morocco are given as illustration in Figures 2.3 and 2.4.

[1] More information at, for example: http://en.wikipedia.org/wiki/Climate_zone

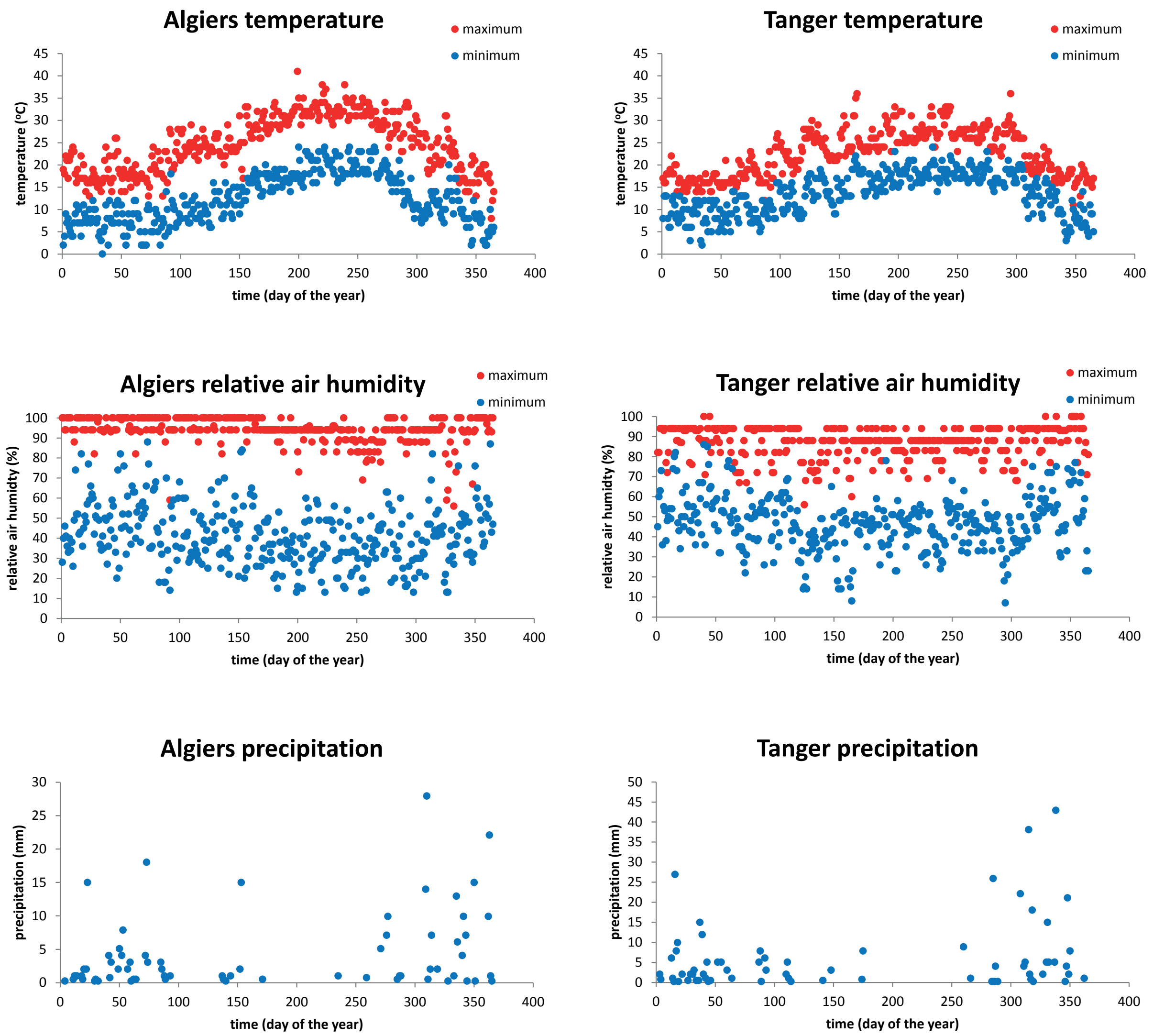

Figure 2.3 *Temperature, relative air humidity and precipitation in two Mediterranean climates in 2014, viz. Algiers in Algeria and Tanger in Morocco. Data source: www.wunderground.com/.*

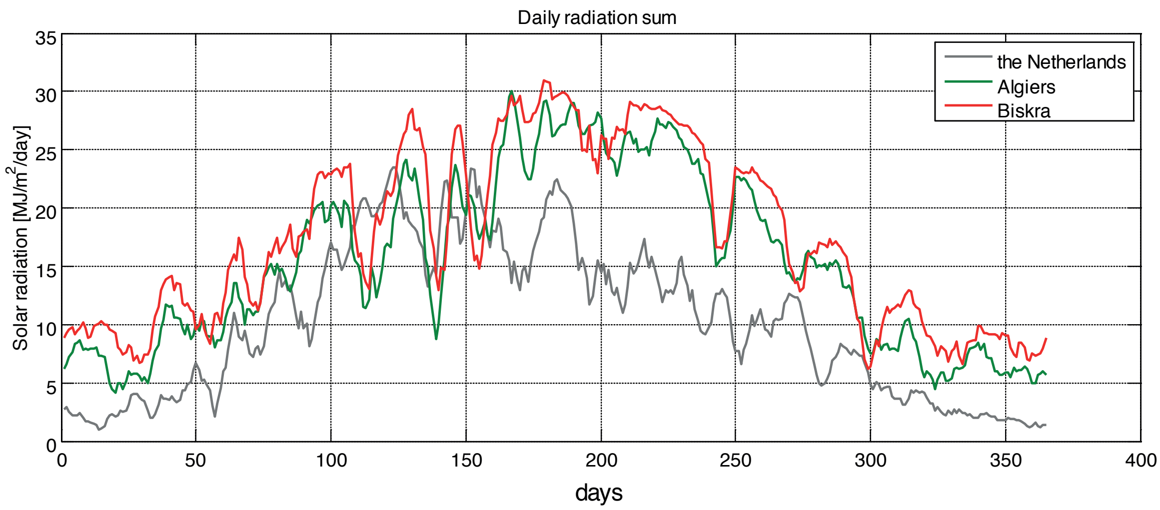

Figure 2.4 *Daily radiation in Algiers and Biskra and the Netherlands in 2011. The data were smoothed by a 7 days moving average filter. Source: van Os* et al. *2012.*

2.2.2 Desert climate

The desert climate has a precipitation that is too low to sustain any vegetation at all, or at most a very scanty shrub. This climate can be found in the rest of northern Africa, and Namibia and Botswana. The climate in Biskra, middle Algeria (south of the Rif mountains) and Cairo, Egypt are given as illustration in Figure 2.5.

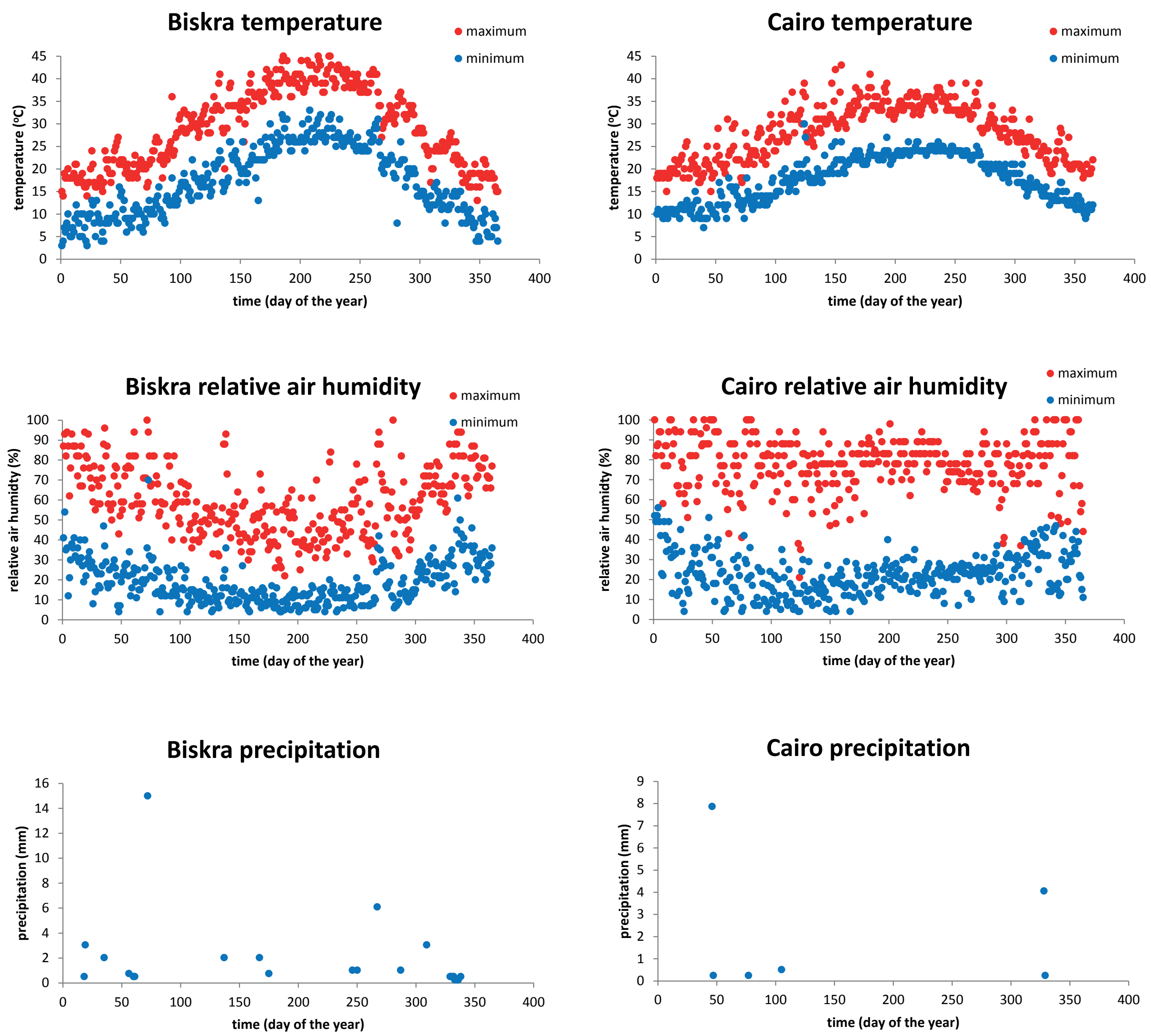

Figure 2.5 *Temperature, relative air humidity and precipitation in two desert climates in 2014, viz. Biskra in Algeria and Cairo in Egypt. Data source: www.wunderground.com.*

2.2.3 Tropical lowland climate

A tropical climate is a non-arid climate in which all twelve months have mean temperatures of at least 18 °C. Tropical temperature remains relatively constant throughout the year and seasonal variations are dominated by precipitation. Examples of this climate can be found in, for example, western Africa. Here, we give the example for Accra in Ghana.

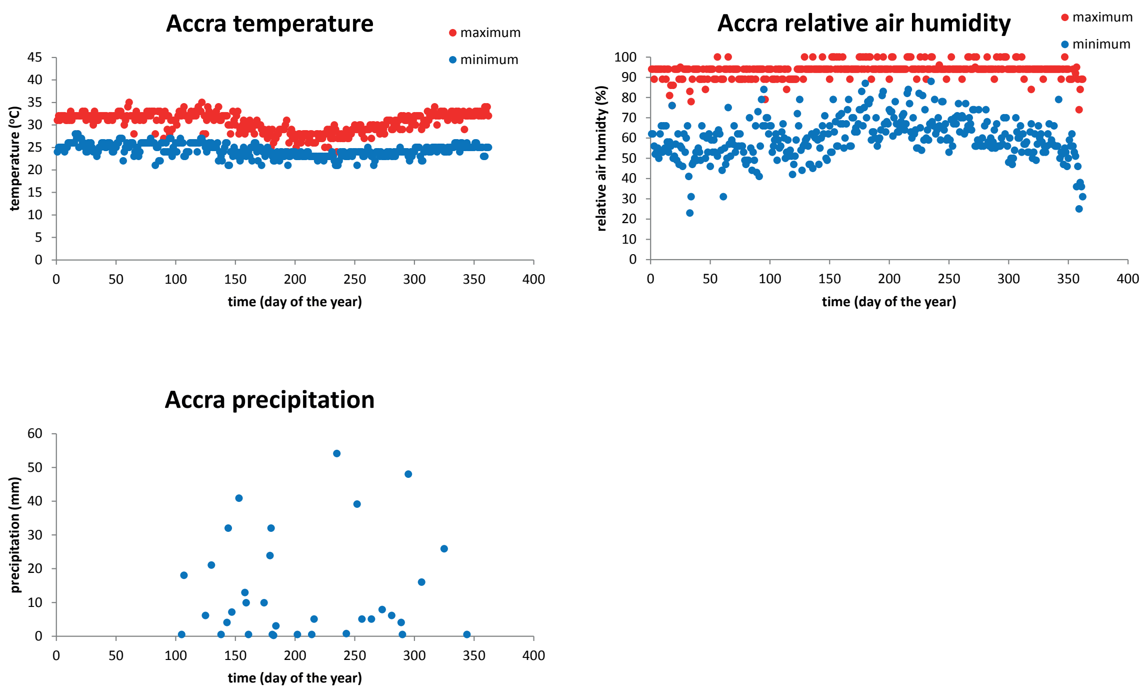

Figure 2.6 *Temperature, relative air humidity and precipitation in the tropical lowland climate of Accra, Ghana in 2014. Data source: www.wunderground.com.*

2.2.4 Tropical highland climate

Temperatures in the tropical highlands are lower than in the tropical lowlands. Temperature is fairly stable over the year, and relative air humidity is associated with the rainfall pattern. Because of the lower temperatures, this climate is suitable for protected cultivation. Most greenhouses in eastern Africa are un-heated. The climate in Naivasha, Kenya and Ziway, Ethiopia are given as illustration in Figure 2.7.

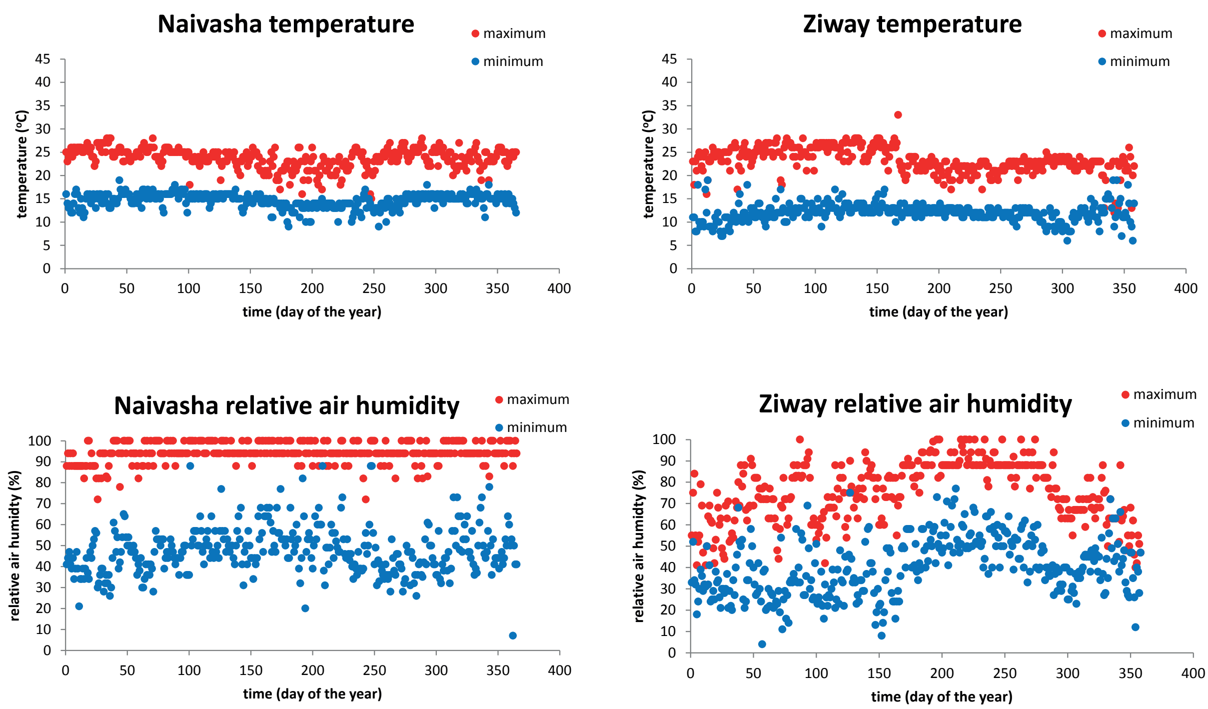

Figure 2.7 *Temperature and relative air humidity (precipitation not available) in the tropical highland climates of Naivasha, Kenya, and Ziway, Ethiopia, in 2014. Data source: www.wunderground.com.*

For illustration, we present in Figure 2.8 the 2008 climate values at three locations in Ethiopia (den Belder *et al.* 2009). In this example, daily outside global radiation varies between approximately 100 J cm^{-2} d^{-1} in the rainy summer season and 275 J cm^{-2} d^{-1} in the dry winter season. Values are fairly similar, except for ET Highland in the winter season, when relatively low values were recorded.

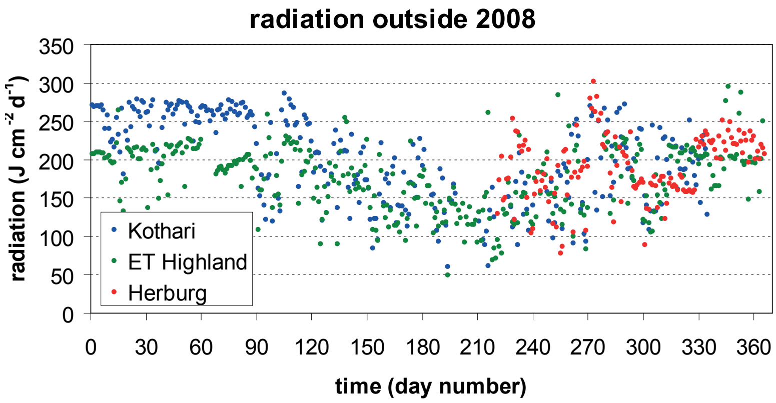

Figure 2.8 *Global outdoor radiation for 2008 (as far as available) at three highland rose farms in Ethiopia. Source: den Belder* et al. *2009.*

2.2.5 Semi-tropical to temperate climate

A temperate climate has an average temperature above 10 °C in their warmest months, and a coldest month average between −3 and 18 °C. The climate of Johannesburg, South Africa is given as illustration in Figure 2.9.

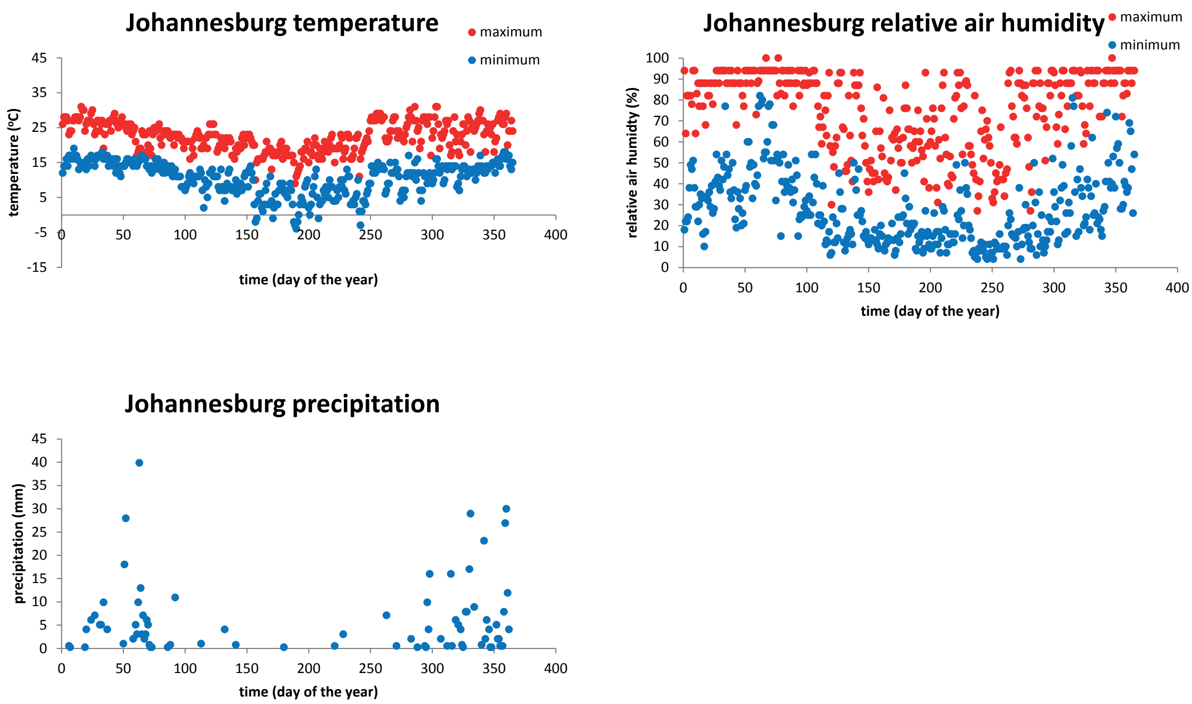

Figure 2.9 *Temperature, relative air humidity and precipitation in the semi-tropical to temperate climate of Johannesburg, South Africa, in 2014. Data source: www.wunderground.com.*

2.3 The economic environment

The price of the product is important from the perspective of greenhouse system design as the costs of the greenhouse construction, the installation, inputs and labour have to be covered by the revenues of the produce. Produce prices usually vary. Export flower prices peak at for example Mothers' Day and Valentine's Day, export vegetable prices are highest if production in e.g., Europe is low, and local vegetable prices peak during the dry season when outdoor production levels are relatively low.

Another important variable is the interest rate, which can be very high in Africa, and which therefore is a critical success factor in the economic sustainability of a greenhouse production system.

It can be difficult to obtain premium prices for greenhouse vegetables in the national market. Consumers are normally not willing to pay extra for a product of higher quality (e.g., less chemical residues, better shelf life) Although the vicinity of customers can have a positive effect on the prices (supermarkets, restaurants and hotels, airline companies). Extra income generally has to be generated through a higher production and/or production during the dry period when prices are higher. Protected cultivation systems give new opportunities to growers in order to access markets at higher price levels.

2.4 The social environment

From the perspective of the envisaged toolbox, the levels of knowledge, skills and capacities are most relevant. High levels are required in protected cultivation. Professional export farms ensure the presence of an experienced farm manager and well-trained staff. However, there are many examples were levels of knowledge, skills and capacities are too low to successfully run a production system. Serious investments in training are required in such cases.

Figure 2.10 *Exchange of knowledge in an Ethiopian rose production greenhouse.*

2.5 The enabling environment

The enabling environment comprises for example rules and legislation that permit (or do not permit) the import of predators to enable biological control, that enforce stringent quality control of chemical crop protection means, that enable a fair flow of money, that enable the smooth import of construction and repair parts, etc. It also comprises the networks that provide electricity, roads that enable transport and water works that guarantee year-round water availability. All these factors influence the pricing and sustainability of a greenhouse production system.

3 Transitions in greenhouse horticulture

3.1 Greenhouse designs

In principle, a greenhouse can be designed for any climate and location. However, economic reasons such as the costs for cooling or heating and logistic considerations such as the distance to customer limit options considerably.

3.2 Options

An African greenhouse, as any greenhouse, consists of the greenhouse construction and the greenhouse installation. Depending on needs and possibilities, the following components can be assembled (the list presented here is an overview that is not meant to be complete). The components are loosely arranged in increasing level of technology.

3.2.1 Greenhouse construction

- *Metal* is the preferred material for construction. Steal and /or aluminium is strong, and the low amount of material increases light transmission. Depending on availability initial investment costs are higher.
- *Wood* is less durable and strong, and therefore, more material is required to realize a solid construction. Consequently, light transmission is relatively low. Next to that maintenance costs are considerably higher.

Figure 3.1 *A greenhouse construction of local wood may be cheap, but is less durable and has lower light transmissivity than a aluminium greenhouse construction.*

3.2.2 Greenhouse cover

- A *net* is not waterproof but provides shade and protects against insects, if entirely closed. The ventilation capacity is depending on the mesh size. The mesh size determines the permeability for insects and air. Net houses are widely found in Africa, with or without closed sides. They are used for, for instance, seedlings, shade plants, ornamentals, etc.
- A *plastic film* protects against rains and insects. It must be combined with ventilation openings to prevent from high temperatures during high irradiation, or a heating installation in situations where temperatures drop (e.g., at night in winter in desert climates). The ventilation openings must be covered with insect nets. Depending on the quality of plastics, the material degrades in time under the influence of UV radiation, high temperatures, chemical or mechanical stresses. Plastic houses are the standard in Africa.

• *Glass* has a longer lifetime than plastic, but has a higher m^2 price if only initial investment costs are considered. It should be considered under high-tech conditions if yields and profits are high and the grower has access to enough initial investment capital.

All greenhouse cover types have their own characteristics with regards to transmissivity and insulation and can usually be found with a wide range of material properties.

Figure 3.2 *Nethouses for seedling raising in Ghana and Kenya.*

Figure 3.3 *Use of greenhouse foil with high transmissivity.*

3.2.3 Climate system

Climate system:

- *Natural ventilation* relies on natural air movement for cooling the greenhouse crop down to outside temperature. Usually, a greenhouse with natural ventilation has sides with nets, and one or two-sided ventilation openings in the top of the greenhouse. These top openings can be fixed or flexible.
- *Circulation fans* can be placed inside the greenhouse to stimulate air circulation. This creates a more homogeneous climate and increases crop transpiration and cooling, but also requires electricity. Ventilation fans can be placed in the side walls of the greenhouse, usually in combination with a pad & fan system (see below).
- *Misting or fogging* is applied to cool and humidify the air. It is especially useful to avoid peak temperatures. In itself, it reduces crop transpiration but the total water use may even increase as the misting or fogging itself requires water (of high quality). The difference between misting and fogging is in water drop size and pressure needed and therefore in the quality of the system performance. Besides application should be in such a way that the crop keeps dry, demanding more than 1 m air space above the top of the crop.
- *Hosing* is a cheap method (if labour costs are low) to maintain air humidity and if water quality is too low for a misting system. Effects on cooling are low.
- *Pad & fan* is also applied to cool the air. It requires both energy and water, and causes a temperature and humidity gradient in the greenhouse.

- A *chiller* is a high-tech system for air cooling that could be applied under such circumstances.
- *Heating* may be required in situations where temperatures can drop (e.g., at night in winter in desert climates).

Figure 3.4 *Natural ventilation (two-side, one-sided).*

Figure 3.5 *Fogging (left) and hosing (right) in greenhouses in Ethiopia.*

Figure 3.6 *An air circulation fan can stimulate air movement in a greenhouse.*

Figure 3.7 *A chiller (in Taiwan) for cooling air.*

3.2.4 Screens

- *Shade screens* are used to reduce the radiation intensity in the greenhouse depending on the shading factor of the material used. If applied outside on top of the greenhouse they are able to reduce the heat load of the greenhouse. They form a barrier for air exchange depending on the material used.
- *Thermal screens* are used to preserve heat in case of low (night) temperatures.
- *Clay or sand covering of the film* as a semi-permanent cover during the season to lower the temperature, but most important reducing light in the greenhouse. It is a widely used and cheap system (fig 3.8, right side).

There exists a wide variety of screens with specific characteristics in terms of light transmission, light spectrum, heat reflection, emission etc.

Figure 3.8 *A high-tech (left) and a low-tech (right) version of thermal screens. In the low-tech version, sand or clay covers the film during the growing season.*

Figure 3.9 *External shading screens (mid-tech greenhouse in Taiwan).*

3.2.5 Energy

Energy is required to operate computers, pumps, screens, and heating and cooling systems if present. Greenhouses with higher levels of technology have more equipment that require energy. Their economic feasibility depends on the balance between the energy costs and the value of the extra production.

- *Fossil energy* mostly used to generate electricity to operate equipment. Diesel, coal (South Africa) is used in for instance desert climates to heat the greenhouse at night.
- *Solar energy* can be captured with solar panels that provide electricity, or solar heat collectors can be installed to generate thermal energy (warm water).
- *Thermal energy* is available at some places, e.g. near lake Naivasha.
- *Wind energy* is an optional energy source to generate electricity.

Figure 3.10 *Use of thermal energy at a farm at Naivasha, Kenya.*

3.2.6 Water

- *Rivers and lakes* are in principle easy sources of water, however, quantities and quality are not always sufficient. Especially during the dry season, water levels in rivers can be very low. This is for example the case in countries such as Kenya, Rwanda and Ghana. Also the quality of surface water is not always good, implying the need for water purification. In Egypt, irrigation water from the Nile river is distributed over large parts of the river delta, however, is not of good quality.
- *Rain and river water* can be collected in reservoirs and be used for irrigation purposes. Greenhouse design should be adapted to collect rainwater. Spreading the water use over time leads to an improved water use efficiency; however, precipitation is often not sufficient for a complete year. Therefore, additional water sources remain necessary.
- *Bore holes* provide water from deeper soil layers. Normally, its quality is better and its supply regular – until the below-ground water resources are depleted.

Figure 3.11 *Irrigation canal in the Nile delta, Egypt.*

Figure 3.12 *On a dam of an artificial lake for irrigation purposes in Rwanda.*

Figure 3.13 *Natural lake and water basin in Ethiopia.*

3.2.7 Substrate

- The *soil* is the most simple and cheapest option. The advantage of soil is its large water availability for the plant. A dysfunctional fertigation system is not directly disastrous to the crop. It, however, also introduces the risks of soil-borne diseases. Bacterial wilt, for example, is wide-spread in Africa, and can completely destroy the crop.
- It is therefore better to grow in pots and combine this with a robust fertigation system (uninterrupted electricity supply!). The pots can be filled with a wide diversity of substrates that each have their own characteristics: soil, coir, pouzzolane, rice husks, pumice etc. Important are the absence of soil-borne diseases, a decent water holding capacity, and maximum chemical neutrality.
- *Slabs* are made of, for example, rockwool that is chemically inert. As in the case of pots, it requires an uninterrupted electricity supply, It is mostly used in combination with a computerized fertigation system.

3.2.8 Fertigation system

- The most simple fertigation system is the *manual application* of water and nutrients. The system is cheap, always works, but is not very precise in terms of amounts of water and nutrients applied.

- *Gravitational fertigation* makes use of a water tank that is placed above field level. The water tank can hold water and nutrients that are mixed in a specific combination, and the water can be applied in specific quantities (the required amount of water and nutrients can be translated to a time period of water flow). The valves of the system are manually operated. The system can be used in combination with for instance drip irrigation.
- *Stand-alone soil moisture sensors* that are accessed with a hand reader are a cheap technology to determine the moment of irrigation.
- A *computerized system* makes use of sensors and a pre-set fertigation regime to apply water and nutrients. It is usually combined with A and B nutrient tanks, and a pH buffering tank. The system obviously requires a non-interrupted supply of electricity. Because of its capacity to provide optimal amounts of water and nutrients, it contributes to improved production and product quality.
- *Recirculation* is applied to re-use water and nutrients. As water resources shrink, this system becomes more appropriate. However, water recirculation introduces the risk of spreading soil-borne diseases and the system therefore requires a disinfection unit (UV, heat treatment, ozon), which is often expensive. Slow sand filtration may be a cheap option for small nurseries. An alternative is to re-use the drain water for outdoor vegetables.

Figure 3.14 *Gravity irrigation in Rwanda.*

Figure 3.15 *A very young rock melon plant, recently transplanted, in a white polybag with cocopeat and a soil tensio meter.*

Figure 3.16 *A fertigation system with drip irrigation at vandenBerg Roses, Naivasha, Kenya.*

3.2.9 Crop protection

Crop protection

- *Biological crop protection* uses a wide array of non-chemical measures prevent and reduce crop infestation, such as strict sanitary measures and predators that prey on the pests.
- *Chemical crop protection* relies on chemical measures. Modern certification system demand that chemical residue levels (MRLs) are below certain standards when the harvest is sold.
- *Integrated crop protection* uses a mixture of biological and chemical crop protection. Chemical crop protection is used as a last resort only.

Figure 3.17 *Studying the application details of biological agents.*

Figure 3.18 *Integrated Pest Management wants to avoid the excess use of chemicals.*

3.2.10 Post-harvest

There are also design options for post-harvest issues such as cooling, grading and packaging that take place at the farm. They all contribute to reduction of post-harvest losses in terms of quantity and quality, which can be very large, and which can therefore add to the income of the grower. We deal with these issues only briefly. An important cooling consideration is the energy that is required. A low-tech solution is evaporative cooling by flowing water over a permeable stone wall and therewith cooling the air that passes. Grading enables the grower to serve for instance a supermarket and a wet market with different qualities at different prices, an good packaging is a necessity to minimise losses during transport.

3.3 Crops

The choice of crop and cultivar (variety) depends on a number of factors, such as market demand and price, climate, skills and knowledge of staff and management, and availability of substrates and other resources. Weighing these factors leads to a proper strategic choice.

The major greenhouse crops in Africa are flowers such as rose, chrysanthemum, and carnations, fruit vegetables such as tomato, sweet pepper, cucumber, melon, chillies, and strawberries, and leafy vegetables.

Figure 3.19 *Roses in Kenya (left) and Ethiopia (right).*

Figure 3.20 *Fruit vegetables in Ghana (left) and Ethiopia (right).*

3.4 Production systems

3.4.1 Outdoor production systems

Although this document focuses on indoor production systems, it is useful to point out that in the African context, outdoor and indoor production systems form an integrated continuum of options for the grower. For instance, a tomato grower may have both fields of outdoor and indoor crops, or may decide to cover the outdoor crop with a simple net – the first step to protected indoor cultivation.

Figure 3.21 *Outdoor vegetable production in Kenya.*

3.4.2 Greenhouse production systems

3.4.2.1 Subsistence farming

In African countries such Rwanda, Ghana, Kenya, South Africa and Egypt most growers have a relatively small farm, of e.g. 100-500 m^2. These growers produce for their own consumption or local market and have a weak linkage with the market. Their investment capacity is low, and they find it is very difficult to obtain bank loans. Their greenhouses are simple without much, if any, technology. If they would move into protected horticulture, it would be doubtful whether they would survive in this role, as their financial model is likely to be unsustainable. Collaboration in co-operatives or collaborating as outgrowers (see below) may be options to strengthen their position. This may, or may not, be associated with some additional technology. This group of farmers is hardly of interest to the Dutch supply industry, but would benefit from good greenhouse designs that can be realized by, for instance, a local blacksmith.

3.4.2.2 Small to medium vegetable and flower2 farms

Small to medium-sized farms (1000 – 5000 m^2) produce for own consumption (in case of vegetables), and also for the domestic market. There is a linkage with the market, but the producers are in a dependent position and can not influence prices. This group includes outdoor growers who are attached to a larger grower who buffers his own production. Because of the stronger linkage with the market or because of the integration in an outgrower-system, there may be more options for investment and increased technology, such as a fertigation system and some screening. Such small to medium-sized farms can be found in for example Kenya, Rwanda, Ghana, and South Africa.

Figure 3.22 *A small tomato production system in Ghana.*

3.4.2.3 Medium to large vegetable and flower farms

Medium to large farms (> 0.5 ha) are of great interest to the Netherlands supply industry. These growers produce vegetables for the domestic, regional and overseas markets, and flowers mainly for the overseas market – only some for the domestic and regional market. These farms are therefore strongly integrated in the market. Because of their size and competitive nature, these farms do have the capacity and need to invest. These farms will typically have an automated fertigation system, fixed or flexible window openings, plastic greenhouse cover, a fairly high knowledge level. Medium to large scale vegetable farms can be found in for example Egypt, Morocco, Ethiopia and South Africa. Medium to large scale flower farms can be especially found in Kenya and Ethiopia.

2 Ornamentals are included in 'flowers'.

Figure 3.23 *A large rose production system in Ethiopia.*

3.4.2.4 Farms growing speciality crops

Some farms in East and West-Africa produce for example fresh herbs and potted plants for the European market. Also breeding companies that impose specific demands to the plants they cultivate, and therefore to the greenhouse and cultivation system, fall in this category. The added value is high, market linkage is strong, and certification is important. The technology level is comparable to that of large flower and vegetable farms, with perhaps the difference that farms that produce speciality crops have even stricter hygiene protocols.

Figure 3.24 *The Olij breeding station at Naivasha, Kenya.*

3.4.2.5 Urban and metropolitan horticulture
Urban horticulture is quite common in African cities. Large cities such as Nairobi in Kenya (van der Lans *et al.* 2012) know various patches of land on which horticulture is practiced. If metropolitan horticulture[3] (which considers a larger geographical region than urban) is considered, the number of farmers further increases. These growers produce mainly for own consumption and for the urban market and may actually be well-integrated with the local fresh market, as logistics play much less a role in comparison with growers that are located at a large distance from the city (in this, there is a difference with subsistence farming). Mostly, the greenhouse constructions, if any, are simple and small.

3.4.2.6 Agroparks
Agroparks that concentrate a number of cooperating supply, production and processing companies and that are characterized by high-tech systems, do not occur in Africa. Collaboration surely exists, but not in the geographically concentrated form that is characteristic for Agroparks. Agroparks may be on the agenda of governments and investors, and it is certainly recommended that the Netherlands supply industry monitors developments. Because, if agroparks are developed, Netherlands knowledge and supplies certainly fit.

3.5 Transitions

Instead of focusing on the current market and level of technology that characterize African farms, it is better to analyse the expected future developments and the transition from current situation to the likely future situation. This enables an analysis of the potential of a certain farm type, the requirements for further development, and the options for Netherlands involvement.

[3] A metropolitan region can in geographical terms be defined as a large population centre consisting of a large metropolis and its adjacent zone of influence. Metropolitan populations are rapidly growing worldwide, having a considerable impact on regional development and even the macro economic development of entire continents (van der Lans *et al.* 2010).

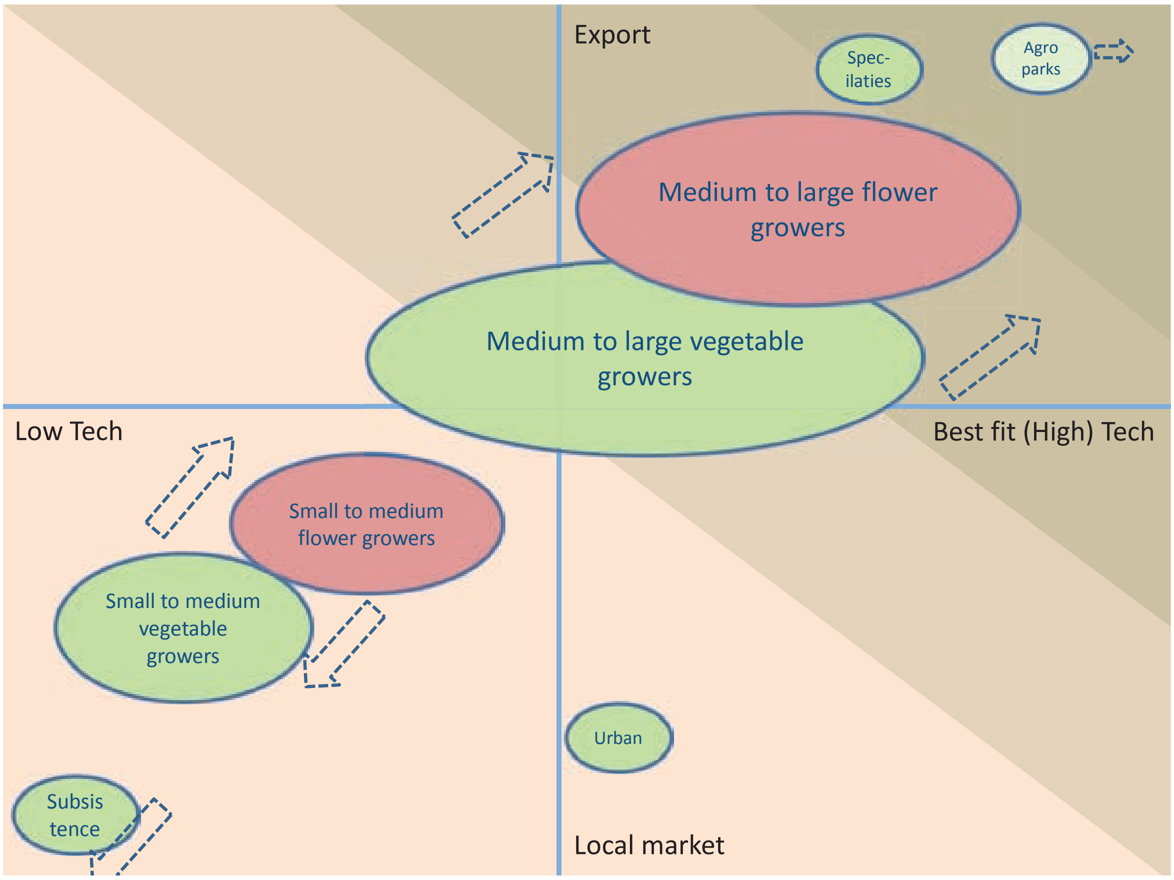

Figure 3.25 *Technology development trends for protected horticulture in Africa. See text for explanation. The size of the oval represents the approximate size of the segment. The arrow gives the assumed development direction of the farm segment. The darker the background colour, the more market opportunities to be found for Dutch input suppliers. Red ovals: flowers; green ovals: vegetables. Based on García Victoria* et al. *2011.*

Transitions in protected horticulture can be visualized in a two-dimensional figure (Figure 3.24, based on García Victoria *et al.* 2011). The x-axis distinguishes farms on the basis of their technology level, and the y-axis does this on the basis of their market orientation. The y-axis moves from local (municipality) oriented to state market, national market and export market. On the whole, farm types move from no and low-tech farms that produce for the domestic market towards high-tech farms that produce for the export market, but this cannot be considered as development path for all farms. Technological levels and markets sometimes coexist in the same, bigger companies, depending on the achieved produce quality. In general, export orientated farms tend to have a larger size. A small sized farm will measure no more than 1 ha; while most medium sized farm will measure 1 to 3 has. A large farm measures more than 10 ha.

1. Small subsistence farms (at least the ones practicing protected horticulture) may in the long run have a difficult future. Much will depend on factors such as the economic feasibility of their production system, the options to obtain and re-pay loans, the options to maintain the greenhouse structure, and on the availability of inputs. Acquisition of more land is unlikely, unless through collaboration in a cooperative or cooperative-like organization. Survival is possible, however, this requires a financial solution for the investments that are needed to start with protected cultivation in the first place.
   The Netherlands supply industry could supply cheap, simple and small greenhouses, seed, and knowledge.

2. It is difficult to forecast developments of small to medium vegetable or flower growers. One option is that they become more market-integrated and move up in technology level, which would offer opportunities for the Netherlands supply industry. In any case, because of the fact that such farms are already somehow market-integrated, they are in a better position than subsistence farmers. However, risks are still substantial. Financial buffers are low, and one or more crop failures (which are not unlikely in Africa) may have disastrous consequences. Also, below-standard performance in terms of production, product quality, marketing may bring such farms quickly in a precarious situation if for example certification requirements are tightened.
   The Netherlands supply industry could also for this group supply cheap and fairly simple greenhouses, seed, and knowledge.

3. Medium to large vegetable and flower farms have a high potential to link better with the international market and increase their technology level. Investment capital is available or can be acquired. As the technology level increases, there is an increasing demand for high-quality greenhouse constructions, installation, seeds, crop protection means and other supplies, and knowledge.
   The Netherlands supply industry could supply above-mentioned items. Long-term relationships characterized by good after-sales by a local office are highly recommended.

4. Speciality farms are attractive customers for the Netherlands supply industry as they are strongly linked with the international market that is very demanding, and as the technology level is relatively high. As the international market only becomes more demanding and more competitive, the Netherlands supply industry could play an important role by making available its high-quality goods and knowledge.

5. Urban markets serve the local market but are integrated with this market. Options for collaboration with the Netherlands supply industry exist, as also the local urban markets in large metropoles are swiftly developing.

6. Agroparks are currently not existing in Africa. The Netherlands supply industry should certainly obtain a role in its long term development.

4 The toolkit

4.1 The adaptive greenhouse approach

Greenhouse design depends on various parameters. The goal is to design a greenhouse that is economically feasible for a specific crop and given location. At the same time criteria such as water use efficiency, energy saving, and food safety can be considered. Using the adaptive greenhouse approach, greenhouse designs are evaluated and compared in terms of crop production, economics and resource use (efficiency) by varying installation parameters like heating, cooling, screening, covering etc. Depending on the market prices year-round production is considered. For every design the resources (energy, water, nutrients, labour, carbon dioxide) needed are calculated. The design also determines the level of food safety (reduced pesticide use) that can be achieved. The quality of labour is also directly related to the level of technology applied in the greenhouse design.

Three models are combined, viz.:
• The KASPRO greenhouse model.
• The INTKAM crop growth model.
• A financial model.

The "adaptive greenhouse" approach (Vanthoor, 2011) is followed, which consists of the following steps:
a. Identification of data sources: climate, production, water use, energy, prices, etc.
b. Definition of objectives: e.g., minimal water use, minimal energy use, high production, and high product quality.
c. Definition of required functions: e.g., energy use, heating, cooling, cultivation systems, crop protection systems, and labour.
d. Description of various economical greenhouse designs.
e. Description of transition paths. These transition paths not only include the greenhouse itself, but also knowledge, institutional infrastructure, post-harvest issues, etc.
f. Workshop with stakeholders to increase awareness with stakeholders from the private and public sector, and define market opportunities.

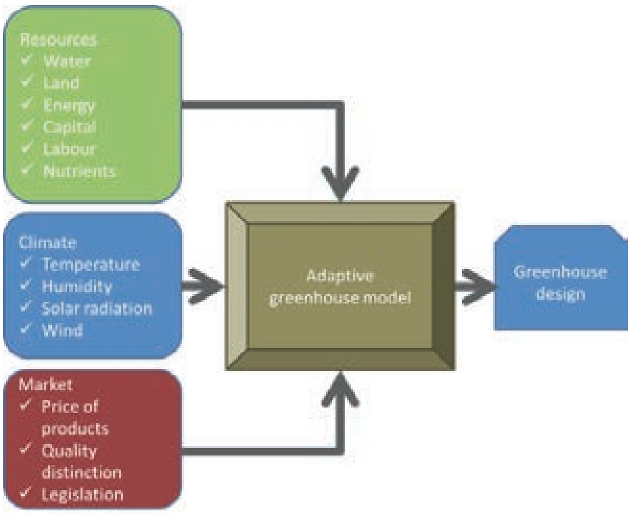

Figure 4.1 *Schematic overview of the approach for the adaptive greenhouse calculations.*

The KASPRO simulation model is based on physical equations describing the heat and mass fluxes associated with greenhouse plant production (De Zwart, 1996). A short description is presented in Annex 1. The dynamic simulations consider all heat and mass fluxes surrounding the greenhouse. A two-minute time step is used to calculate the dynamic process and recalculate all state parameters such as for example the greenhouse temperature. The greenhouse air temperature, canopy temperature, relative humidity, transpiration etc. are all calculated for a specific time period. All the resources used, such as water, energy and CO_2 are calculated. The production is also modelled in terms of dry matter production, which can be translated into fresh produce. The models have been validated with experimental data over the years and have been extended describing the economic implications (Vanthoor, 2011).

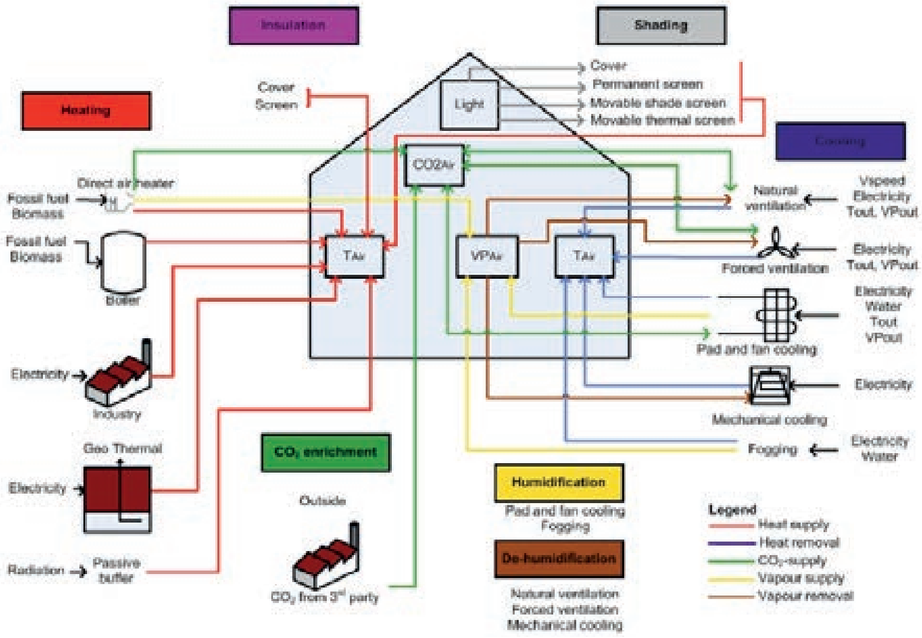

Figure 4.2 *Visualization of the dominant fluxes and states used in the KASPRO dynamic greenhouse simulation model.*

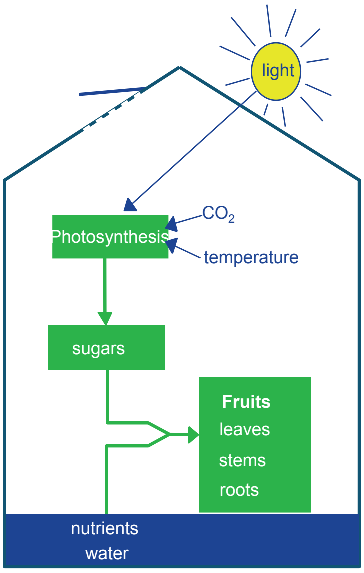

Figure 4.3 *Visualisation of the Intkam crop growth simulation model.*

The Intkam model simulates growth and development of a number of greenhouse crops, amongst others of tomato. Crop photosynthesis rate is computed at small time steps (5-60 min) with a biochemical model on the basis of radiation, CO_2, temperature and relative air humidity. Instantaneous rates are integrated to a daily crop photosynthesis rate. Daily dry matter partitioning and organ growth rates based on the sink strengths of various organs and assimilate availability (Marcelis *et al.* 2006). Crop transpiration rate is simulated in a similar manner. Intkam simulates the number of trusses (and fruits) on a daily basis, and the daily weight of harvested fruits. These processes also depend on the environmental conditions.

The financial model takes into account investment costs, interest rates, maintenance and depreciation costs, variable costs, market prices of tomatoes, and realized production. The model computes gross and net incomes, and pay-back period of the investments.

4.2 Examples

Wageningen UR Greenhouse Horticulture has been involved in projects in which greenhouses for different climates were designed. A selection is presented in this section.

4.2.1 Algeria: Mediterranean and desert climate

Figure 4.4 *Algerian greenhouses.*

Greenhouse designs in two regions in Algeria were investigated, viz., the coastal zone with a Mediterranean climate (Algiers) and the sub-desert region of Biskra, south of the Rif mountains, and a gateway to the Sahara (van Os *et al.* 2012). Both regions have a substantial greenhouse area.

Radiation in Algiers (6.5 GJ m^{-2} y^{-1}) and Biskra (7.2 GJ m^{-2} y^{-1}) is much higher than in The Netherlands (3.8 GJ m^{-2} y^{-1}) and, consequently, the potential yield is also much higher. High summer temperatures reduce the length of the growing season. Temperatures in Biskra frequently exceed 35°C which results in a shorter growing season than in Algiers. Average annual precipitation in Algiers and Biskra are 550 mm and less than 200 mm, respectively. Although rain falls in peaks it is possible to collect rainwater and to cover the water need in a season for 75 - 85% with a 1000 m^3 ha^{-1} reservoir. For soilless cultivation rainwater collection is strongly recommended to achieve an excellent water quality at which additional (ground)water, with an insufficient quality, still can be used. Wind speed at day time is mostly more than 2 m s^{-1}, which is sufficient for natural ventilation. Heating can be useful at both locations as minimum temperature drops frequently below 10°C, while 15°C can be considered as an acceptable minimum temperature.

Three greenhouse types were investigated, viz. single span tunnels, Canarian greenhouses and multispan tunnels.

With regards to a single span tunnel:
- Limited ventilation (3% in front and back door) can be improved to 30% by side wall opening over the whole length. Openings can be covered with insect nets against Tuta absoluta. Nets against other insects decrease the ventilation rate too much.
- A cover material should be a thermic film with high transmission (>75%) realizing diffuse light in the tunnel and should be strong enough to resist strong wind peaks in especially the Biskra area.
- In Biskra adiabatic cooling (pad & fan) is able to reduce the inside temperature with 10°C. In Algiers, which has a more humid climate, pad & fan cooling is not recommended.
- Shading in Biskra with a sand/mud mixture decreases light more than temperature and should be minimized, as otherwise production suffers. Gradual dosing the sand/mud mixture and measuring the light intensity is recommended.
- The payback time of improved ventilation rate by larger windows will be about 1 year and is recommended above the use of pad & fan cooling.
- Heating is not recommended, although temperatures drop below 15°C.

The Canarian greenhouse is preferred over a multispan tunnel:
- Recommended if outside relative humidity and precipitation is low. This type is not recommended for the Algiers region but may function very well in the Biskra area.
- Because its low investment (€20 m^{-2} for the Canarian greenhouse and €40 m^{-2} for the multispan tunnel).
- Yields are in the Canarian house somewhat lower than in the multispan tunnel, resulting in comparable economic benefits.

With regards to a multi-span tunnel:
- Ventilation capacity (currently between 10 and 15%) should be increased to around 40%. Openings are covered with insect nets mainly against Tuta absoluta.
- Glass or plastic cover? A multispan covered with a plastic film is much cheaper with lower yields and slightly lower revenues, which will be acceptable. Maintenance and repairs are easier to realize for a plastic than for a glass cover. If capacity building is well organized to achieve the high potential yield to balance high investments glass can be used. The lifespan of a glass house (10 y) is much longer than that of a plastic cover (2.5 – 3.5 y).
- Shading by a movable screen (30% open, 70% closed strips) is recommended.
- Heating is needed and if a pipe/rail system is placed, this can be used for internal transport. If heating is available via a burner, CO_2 application is possible, especially when a buffer for heat storage during the day and usage at night of 150-200 m^3 ha^{-1} is available. 60-80 W/m^2 is needed to keep the multispan above 12°C during most of the cold days.
- The additional investments in greenhouse improvements are all economic interesting. Larger windows and the combination of larger windows, cooling and heating/CO_2 show the best results.

A substantial amount of rainwater can be collected from the greenhouse cover (75 - 90%) in Algiers which has an annual rainfall of 500-600 mm. The required facilities for rainwater collection in Biskra are less because of the low rainfall (< 250 mm; no details available). This type of water is of excellent quality and is used for soilless growing methods. A reservoir of 1000 m^3 ha^{-1} is recommended.

The production level in the greenhouses can be increased by optimising different factors. Most important is the production period, followed by light transmission, temperature control and soilless cultivation. Technically this can be achieved, but cultivation skills have to be improved. In both single span and multi span greenhouses a number of factors can be improved to achieve a fast growth in production level: the training system of the plants, internal transport, soilless cultivation. Two crop cycles should be avoided, if possible one crop per year is more efficient.

Economic calculations show that improved ventilation with large windows in both a single and a multispan tunnel give the best extra net economic result in both regions. The payback period of the single tunnel with large windows is one year. Large windows in a multispan tunnel greenhouse hardly require an extra investment in case of new establishment. A multispan tunnel with large windows, a pad & fan system and heating/CO_2 also gives good financial results. The extra net result in Biskra is even larger than the multispan tunnel with large windows. This multispan tunnel design requires a high extra investment (ca. 2400 US$ m^{-2}) with a payback period of more than 3 year. A pad & fan system (for cooling) added to a (single or multispan) tunnel greenhouse with large windows has a negative effect on the financial results, although the pad & fan system gives a better financial results in the (dry) Biskra region than in the (humid) Algiers region in for both the single tunnel as well as the multispan tunnel greenhouse.

4.2.2 Emirates: desert climate

Wageningen UR Greenhouse Horticulture is involved in the Middle East setting up research centers in the field of water saving with the aim to test and demonstrate water-saving technology under local conditions. Three different levels of technology are considered being the current technology (low tech), improved technology (mid tech) and the most advanced technology (high tech). The technology for soilless cultivation with possible recirculation of drain water is an important topic in these centers and can be implemented on all levels of technology as a first step in water saving. Water is not only used for the plants though, a larger part is used for cooling, evaporative cooling in this region. Due to the relatively low humidity this form of cooling works well but the water consumption is high. This technology is improved by distributing the air more homogenous over the greenhouse and regulating the solar radiation entering the greenhouse depending on the climate conditions (mid tech). The most advanced technology (high tech) allows full control of the climate. Obviously this type of technology consumes more energy, but it also gives way to a higher production of a better quality. The technical and economic feasibility of these innovations will be researched at these centres. But also the practical application is taken into consideration specially in the area of needed expertise.

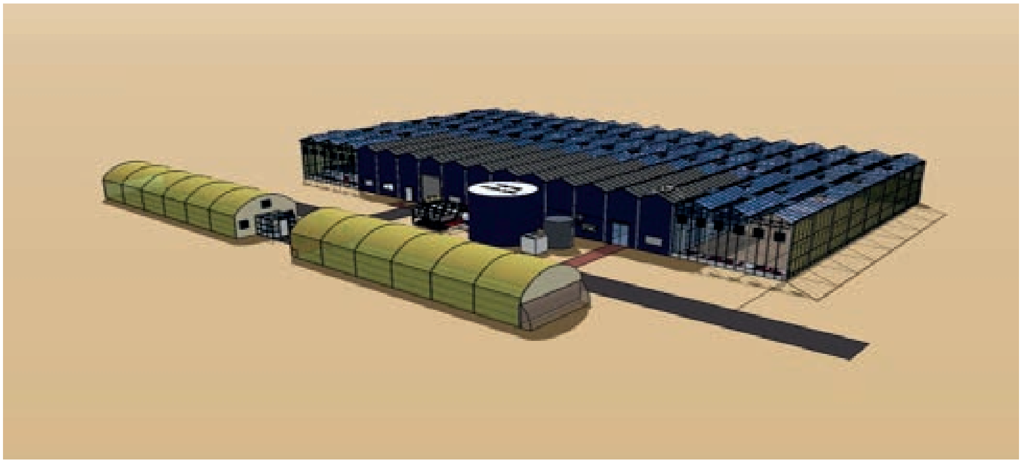

Figure 4.5 *Design for a research centre in the Emirates.*

4.2.3 Indonesia and Malaysia: tropical lowland climate

A greenhouse was developed for a tropical lowland climate and evaluated in Indonesia (Impron, 2011) and Malaysia (Elings *et al.* 2012). A high natural ventilation rate was required. Mechanical cooling was not an option because of the high energy costs and unavailability/uncertainty of availability of electric power. The greenhouse has a three-span cover and tilted side walls with insect nets to reduce air resistance and top vents allowing hot air to leave the greenhouse, especially in no-wind conditions that occur frequently around noon. The top vents have a 'chimney' construction that allows the passing of wind, which stimulates the air flow from the inside of the greenhouse. The covering of the greenhouse should reduce direct solar radiation by making the light penetrating the greenhouse diffuse, which reduces high temperatures in the top of the canopy. The greenhouse has insect nets at all openings and a double-door sluice to prevent insects from entering. The ground is covered with white plastic to prevent the growth of weeds and soil-borne diseases, and plants are grown in white polybags filled with locally available cocopeat. The greenhouse is equipped with a computer installation that can manage the application of water and nutrients ('fertigation') on the basis of the climate and the needs of the crop. All construction materials were obtained locally, which reduces costs. Only the computer has to be imported. It is tempting to reduce costs by using cheaper materials, to reduce the height of the greenhouse and therewith to reduce the amount of materials needed, or not to install a computer system. However, this will lead to a shorter life span, an adverse climate, and low yields. The consequence is that no profit is made. Reduced investments result in even greater losses of profit.

Figure 4.6 *A view of the tropical greenhouse at the premises of EastWest Seed Company at Purwakarta, Indonesia (left), and at those of the Department of Agriculture in Serdang, Malaysia (right).*

4.2.4 Taiwan: subtropical climate

The subtropical climate in Taiwan is characterized by maximum temperatures between 25 and 35°C. This requires a high ventilation capacity to maintain greenhouse temperatures that do not exceed outdoor temperatures. A ventilation capacity of 30% considerably reduces the number of hours with temperatures above 35°C. If insect nets against white flies are placed, a ventilation capacity of 40% is required. Winter minimum temperatures can be as low as 5°C but normally are between 10 and 20°C. In summer, minimum temperatures are approximately 25°C, and is night-time relative air humidity high. Day-time relative air humidity is a little lower, which makes adiabatic cooling through fogging possible. Computations show that with a fogging capacity of 300 g m^{-2}, the maximum air temperature exceeds 32°C only for a few hours during day-time. Air circulation during night-time reduces the risk of condensation on leaves and stems. Installation of a small heating unit provides an additional option to reduce condensation in winter. Supplementary CO_2 application is economically not useful, as most CO_2 leaks away through the large ventilation openings.

The final greenhouse is design is of the Venlo type with a span width of 4.8 by 4 m, has a very diffuse cover of non-thermic foil with a high light transmission, good light scattering and low night temperatures. The natural ventilation is high to avoid high air temperatures during periods with high radiation and high outdoor temperatures. Two-sided roof ventilation in combination with side ventilation ensure greenhouse temperatures that do not exceed outdoor temperatures. All ventilation openings are covered with white fly insect nets. Additional cooling is supplied by a high-pressure fogging system to reduce greenhouse temperature through water evaporation (adiabatic cooling) and to avoid low air humidity during day-time. An air circulation system reduces condensation on stems and leaves during nights with high relative air humidity. A computer manages the greenhouse climate and fertigation.

Figure 4.7 *Mid-tech greenhouse with cultivation of cherry tomato in the subtropical climate of Taiwan.*

5 Activity Plan

The final goal is to realize 2-3 projects in different climate zones for demonstration of technology, knowledge transfer and training.

Activities:
1. Make leaflet.
2. Obtain feedback from within Wageningen UR, e.g., Wageningen International.
3. Obtain feedback from others, outside Wageningen UR, e.g., Agricultural Counsellors.
4. Round table discussion to contact interested companies and platforms, such as:
    a. Greenhouse construction companies (e.g., Bosman van Zaal, Rovero).
    b. Fertigation companies (Genap, HortiMaX, Priva, Hoogendoorn).
    c. Screen and net companies (Howitec, Ludwig Svensson).
    d. Breeding companies.
    e. Crop protection companies (e.g., Koppert).
    f. GreenFarming.
5. Concrete project proposals (or leads).
6. Further development of the 'Toolbox Adaptive Greenhouse Systems for Africa'.
7. Organize financing:
    g. PPS / Topsector T&U.
    h. RVO mechanisms.
    i. African investors.
    j. International donors, e.g., Clinton Foundation, Agra

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Annex 1 Climate acronyms

Af: equatorial climate

Am: monsoon climate

Aw: tropical savanna climate

BWh: warm desert climate

Bwk: cold desert climate

Bsh: warm semi-arid climate

Bsk: cold semi-arid climate

Csa: warm mediterranean climate

Csb: temperate mediterranean climate

Cwa: humid subtropical climate

Cwb: humid subtropical climate/subtropical oceanic highland climate

Cwc: oceanic subpolar climate

Cfa: warm oceanic climate/humid subtropical climate

Cfb: temperate oceanic climate

Cfc: cool oceanic climate

Dsa: warm continental climate/mediterranean continental climate

Dsb: temperate continental climate/mediterranean continental climate

Dsc: cool continental climate

Dsd: cold continental climate

Dwa: warm continental climate/humid continental climate

Dwb: temperate continental climate/humid continental climate

Dwc: cool continental climate/subarctic climate

Dwd: cold continental climate/subarctic climate

Dfa: warm continental climate/humid continental climate

Dfb: temperate continental climate/humid continental climate

Dfc: cool continental climate/subarctic climate

Dfd: cold continental climate/subarctic climate

ET: tundra climate

EF: ice cap climate

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

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Greenhouse Horticulture Report GTB-1360

Wageningen UR Greenhouse Horticulture initiates and stimulates innovations for a sustainable protected horticulture and a better quality of life. This is achieved by partnering with primary producers, the supply sector, plant breeding companies, the scientific community and governments in applied research.

The mission of Wageningen UR (University & Research centre) is 'To explore the potential of nature to improve the quality of life'. Within Wageningen UR, nine specialised research institutes of the DLO Foundation have joined forces with Wageningen University to help answer the most important questions in the domain of healthy food and living environment. With approximately 30 locations, 6,000 members of staff and 9,000 students, Wageningen UR is one of the leading organisations in its domain worldwide. The integral approach to problems and the cooperation between the various disciplines are at the heart of the unique Wageningen Approach.