WAGENINGEN UR
For quality of life

Modern, sustainable, protected greenhouse cultivation in Algeria

BOCI nr: BO-10-030-011

Projectnummer: 324 215 5300; LEI: 227 500 057

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Ministerie van Economische Zaken

Rapport GTB-1263

Acknowledgements
This research was financed by the Dutch Ministry of Economic Affairs (BO-10-030-011; Niek van Dijk, Marijke Langeveld). For visiting Algeria the help of the Dutch embassy in Algiers was very useful. Thanks to Mr Khaled Benchaal and Mrs Isabel van Tol, we greatly appreciated your help in organising our trips, translating where needed and helping where possible.

We are thankful to Mr. Meirink from KNMI (meirink@knmi.nl) for supplying the radiation data that are used for our simulations.

Besides it should be mentioned that cooperation between this BOCI project and the G2G project (G2G10/AG/8/2 IMPROVEMENT OF HORTICULTURAL PRODUCE ALGERIA) was logical and very useful; Mr Allard Andela, Vrian). It gave the opportunity to visit Algeria more often and to exchange knowledge between interested parties. The training, part of G2G, of staff of ITCMI and the workshops with private companies gave useful insights into the Algerian society, the way of thinking and, consequently, the needed way of acting in this remarkable republic of Algeria, which can hopefully be continued in a following project.

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Inhoudsopgave

Summary

The goal of the project was to analyse the structure and technology level of protected cultivation in Algeria, which were followed by recommendations for improvements (technical, cultivation and economic aspects) of existing and newly built greenhouses. Further, in discussion with Dutch and Algerian parties, the goal was to come to a final design which can be built with local partners. The Wageningen UR “adaptive greenhouse approach” was used at which results of the simulation models for the greenhouse design, the water use and the economic feasibility were integrated to clear recommendations. Results and recommendations were presented to representatives of the Algerian government, local greenhouse entrepreneurs and growers. There was strong cooperation between the two ministry projects (G2G10/AG/8/2; BOCI, BO-10-030-011).

Actual situation

Two horticultural regions appeared to be important for protected cultivation, Algiers representing the Mediterranean coastal zone and Biskra representing the semi-desert area south of the Rif mountains. Biskra receives about 15% more light than Algiers, and both about 50% more compared to The Netherlands, consequently, the potential yield in Algeria is higher than in The Netherlands. However the temperatures in Algeria are often too high (T> 35 °C) or too low (< 10 °C), both shorten the growing season. At the same time relative humidity is low or too high causing stress in the plants or susceptibility for plagues and diseases. Around Algiers it is much more humid, while in Biskra humidity is very low. Precipitation appeared to be on average around 550mm in Algiers, but scarce in Biskra, while wind direction in Algiers is variable, in Biskra often northwest or southeast.

Present greenhouse horticulture is mainly in single tunnels which are often grouped in larger numbers. Partly there are multispan tunnels and Canarian greenhouses. Model simulations with the simple tunnels showed that the present ventilation rate of 3-5%, the first with openings only in front and back, the latter with additional small holes in the side wall, is too little to control temperature. An increase of the ventilation rate to about 30% is needed and can be realized by complete opening of the side walls. After realizing, the potential yield will increase about 50% by extending the length of the season. A diffuse thermic plastic cover with a high light transmission is recommended. Evaporative cooling (pad & fan) is only recommended for Biskra with its low relative humidity. Temperatures will drop by about 10 °C, but much water for cooling is needed. Shading should be minimised to about 20% to avoid too low light levels.

Type of greenhouse

Single span tunnels can be dramatically improved by increasing the ventilation rate up to 30-40% (0.3- 0.4 m^2 opening per m^2 greenhouse area). Preferably the windows will be closed in cold nights and during winter. The cover should be a plastic film that is diffuse and has a high transmission of light. In Biskra pat & fan cooling is a good option; in Algiers it is too humid. Shading will help to reduce too high temperatures, but not more than 20% reduce in light transmission should be realized. Rainwater collection in Algiers region is a good way to achieve good quality water.

For multispan tunnels the ventilation rate should be increased to above 30% to minimize the number of hours that temperatures rise above 30 °C. However insect nets are recommended to avoid penetration of Tuta absoluta (minor reduction of ventilation rate) or white fly and thrips (major reduction of ventilation rate). Fogging can be helpful to increase humidity in Biskra and to cool the air. In Biskra pad & fan is also useful. CO_2 dosing, up to outdoor level, is useful in both regions and giving more effect in Biskra (also more light). A screen to shade and to keep heat inside during the night is useful, but as a permanent screen decreases production level with about 30%, a movable screen is recommended (decrease of production about 10%). A heating capacity of 80 W/m^2 is needed to keep temperatures above 12 °C for the whole year, which can also supply CO_2. A larger boiler is needed to realise a minimum temperature of 15 °C, which is recommended for cultivation reasons. If sufficient space is available a heat buffer on solar energy is a low but useful investment. For Biskra conditions a Canarian greenhouse can be used too (cheaper) because the RH is low. In Algiers the Canarian greenhouse gives too high humidities and drip of water and should not be used.

Cultivation measures

With a precipitation between 500-700 mm in Algiers rainwater collection from the cover is quite useful and may cover the water need for about 65% (250 m^3/ha/yr) to 85% (1000 m^3/ha/yr storage capacity). Larger basins are not needed.

If soilless cultivation is used with recirculation the use of rainwater eliminates the need of discharge for tomato, but not completely for sweet pepper based on relative high sodium concentrations in rainwater (0.3 mmol/l) and additional water (4.0 mmol/l).
A number of cultivation measures could be taken to a further increase of production. Most important is to change to soilless cultivation in a local (cheap) substrate of excellent properties with use of rainwater. The use of an older plant to be planted in the greenhouse, internal transport (preferably with a heating system, training of plants and as long as possible to continue with one crop per season are other factors to increase production. All factors which extend the growing season are quickly economic.
Present investment level in greenhouses in Algeria varies between € 4.2 for a single tunnel (no plastic cover) to €20 for a Canarian greenhouse and €40 for a multispan tunnel. Estimated yield varies from 8 to 18 and 25 kg/m^2, respectively. In all three greenhouses the cost price is about € 0.22/kg fresh tomato.

Economics

The economics of an improved greenhouse, both single tunnel and multispan tunnel, are estimated. For the single tunnel the use of large windows (extending the ventilation capacity) is most economic (pay-back time less than one year and best extra net result). The use of larger windows in combination with pad & fan cooling is economic, but only marginal. Large investments are needed to achieve a higher yield. For the multispan tunnel an investment in a larger ventilation capacity is doing well, but recommended is an investment in larger windows in combination with cooling, heating and CO_2 dosing (pay-back time less than 4 years). Outcomes mentioned are valid for both regions Algiers and Biskra.
Algeria mainly delivers on its own home market (35 million inhabitants), there is hardly export of greenhouse vegetables. Delivery mainly goes via whole-sale markets. It appeared that sorting, grading, cooling and packing is only limited available. To achieve higher prices, especially for produce from an improved greenhouse, the aspects mentioned should be improved to extend the life span of the produce.

Generally it can be said that single tunnels can be improved for growers with a low investment level, but increase in production is quite well possible. For growers with more money to invest, multispan tunnels are much better. In both cases the skills of the staff have to be improved adequately.

Marketing

The postharvest situation and marketing of greenhouse vegetable products in Algeria is not yet optimal. Sorting and grading is implemented at a low profile, packaging is mostly simple and cooling of products from grower level to retail/ consumer level hardly takes place. To improve the market position of Algerian growers different opportunities are available: grading, packing, cooling, product diversification and export.

1 Introduction

1.1 Motivation and goals

As a result of the recent social and political developments in North Africa, the European Union and the government of the Netherlands have initiated / redefined sets of interesting instruments to assist the social, political and economic climate of the region (Transit Arabic region). One of the main is to support the international economic policy of the Dutch government. Some of these instruments such as PSI (Private Sector Investment program) allow and stimulate the Dutch SME to look further beyond the borders. Algeria is one of the countries explicitly mentioned.
This study will provide the private sector with reliable information and assists SME's of the both countries to boost trade and investment in a modern, sustainable horticulture sector in Algeria as part of the Green farming approach of GHI as part of the international strategy of the Topsector Tuinbouw + Uitgangsmaterialen. The aim is to set up a PPP for the realization of a practical greenhouse system for Algerian conditions based on the so called SMASH concept of GHI: Smart Sustainable Horticulture, the development of horticultural production using adaptive greenhouse systems, fitting the specific conditions of a specific region.

Project goals:

- Create an enabling environment for the development of modern and sustainable protected cultivation in Algeria with active engagement of the Dutch technology and Dutch know-how.
- Contribution to the international policy of the Dutch government related to the sustainable chain and 3 golden triangles.
- Active participation in the demand and the need of the Algerian government regarding modernization of Algerian horticulture sector, capacity building, research, transfer of knowledge.
- Comply with the request of the Algerian ministry of Agriculture and Rural Development for bilateral cooperation on modern horticulture as mentioned in the signed agreement in 2010 between the two countries.
- Road map and set up of a public private partnership including Algerian Investors to realize a demonstration/ production facility.

Description of activities

1. Analyzing structure and technology level of protected cultivations in Algeria, availability of irrigation water and energy sources, determine climate circumstances (year round, 24 hours); writing a report.
2. Definition the pre-conditions for the greenhouse system, using information on the outside climate, availability of energy and water, target level of sustainability and economic earning capacity.
3. Design and comparison of different designs in terms of sustainability and economic feasibility. In the design phase different technology levels are used to determine the optimal system given the preconditions. The "adaptive greenhouse approach", developed by Wageningen UR is followed using simulation modeling combined with economic feasibility based on the local price levels and market conditions.
4. Consultation of representatives of the Dutch horticulture suppliers about the desired design, writing final report.
5. Meetings with representatives of the Algerian government, potential investors, and the Dutch horticulture trade and industry in which the possibilities of modern protected cultivations are discussed and agreements are made upon the follow-up.

In this report the results are presented of the above-mentioned activities.

1.2 Background

Protected cultivation systems are used throughout the world for crop production. Areas with protected cultivation are still growing. Driving forces range from improved food production with higher production levels, extended growing seasons, decreased water use compared to open field production and/or diminished risks of crop failure by for instance storm, rain

or hail and pests and diseases, to better quality and safer food products and a growing demand for convenience products like specialties, flowers and potted plants.
A scan of the systems used throughout the world reveals that a wide range of protected cultivation systems has evolved that fit local circumstances. These solutions range from low-tech, low-cost plastic tunnels to high-tech expensive glasshouses used in Western-Europe and North-America. Greenhouses differ in size, shape and materials used, ranging from single span structures covered with plastic to multispan greenhouses with glass covers. Instrumentation ranges from unheated greenhouses with natural ventilation to production systems with computer controlled heating, cooling, humidification and dehumidification, CO_2-supply and artificial light. Even fully closed greenhouses with mechanical cooling are built in for example The Netherlands and the Middle East. Crops are grown in soil, but also in artificial substrates with water and nutrient supply using drip irrigation and closed water circuits with drain water recycling. Manual labour is commonly used throughout the world, but in high-tech greenhouses the first robots have recently been introduced to replace human labour.

With these observations in mind, this study addresses the design of a protected cultivation system that satisfies the local conditions in Algeria. Definitely, this question is not raised for the first time. An abundance of literature exists in which various design issues have been tackled, related to greenhouse structure and greenhouse covering materials (*e.g.* Von Elsner *et al.* 2000a,b), to optimize the greenhouse design to one specific location or to one single construction parameter (Campen 2005; Zaragoza, Buchholz *et al.* 2007), to optimize climate conditioning (*e.g.* Garcia *et al.* 1998), greenhouse climate control (*e.g.* Bakker *et al.* 1995) or substrates and nutrition control (*e.g.* Gieling, 2001), to mention just a few examples. In most of these studies greenhouse design is approached as a single factorial problem, which means that only one issue is being considered which may lead to a sub-optimal design. However, the design of protected cultivation systems is a multi-factorial design and optimization problem (van Henten, Bakker *et al.* 2006), thus multiple factors have to be addressed to find the optimum design.

The question raised in this study is: *What is the optimum greenhouse design for vegetable growing in Algeria?* Our goal is to realise an environmentally friendly production system with low energy input, use of sustainable energy where possible, high water use efficiency, high production and predictability of production, high product quality, high food safety and good ratio of benefit and costs of the production system.

One of the most important factors influencing the optimum greenhouse design is the climate of a location. The weather strongly influences the greenhouse inside climate and therefore crop production inside the greenhouse to a large extend. Hanan (1998) and Van Heurn and Van der Post (2004) have identified some other factors that determine the particular choice of the protected cultivation system used. A combination and extension of their lists of factors:

1. Market size and regional physical and social infrastructure which determines the opportunity to sell products as well as the costs associated with transportation;
2. Local climate, which determines crop production and thus the need for climate conditioning and associated costs for equipment and energy. It also determines the greenhouse construction dependent of, for example, wind forces, snow and hail;
3. Availability, type and costs of fuels and electric power to be used for operating and climate conditioning of the greenhouse;
4. Availability and quality of water;
5. Soil quality in terms of drainage, the level of the water table, risk of flooding and topography;
6. Availability and cost of land, present and future urbanisation of the area, the presence of (polluting) industries and zoning restrictions;
7. Availability of capital;
8. The availability and cost of labour as well as the level of education;
9. The availability of materials, equipment and service level that determines the structures and instrumentation of the protected cultivation systems;
10. Legislation in terms of food safety, residuals of chemicals, the use and emission of chemicals to soil, water and air.

The focus in this study will be on the design of an adequate greenhouse for low-tech growers (a single tunnel) and on a high-tech greenhouse for growers with space for investment with good prospects for growers in the field of technical development, cultivation and economic and marketing development (nrs 1, 2, 3, 4, 7, 8, 9 and 10. Nrs 5 and 6 were of less importance for this study. This approach will cover the developments of Algerian greenhouse cultivation in the past and, probably, in the near future.

1.3 Location of the greenhouses

Two locations within Algeria, Algiers and Biskra, show important concentrations of greenhouses (Figuur 1.1.). Algiers is at the coast and has a Mediterranean climate. Biskra is at the Southside of the Atlas mountain range and has a warmer, arid climate.

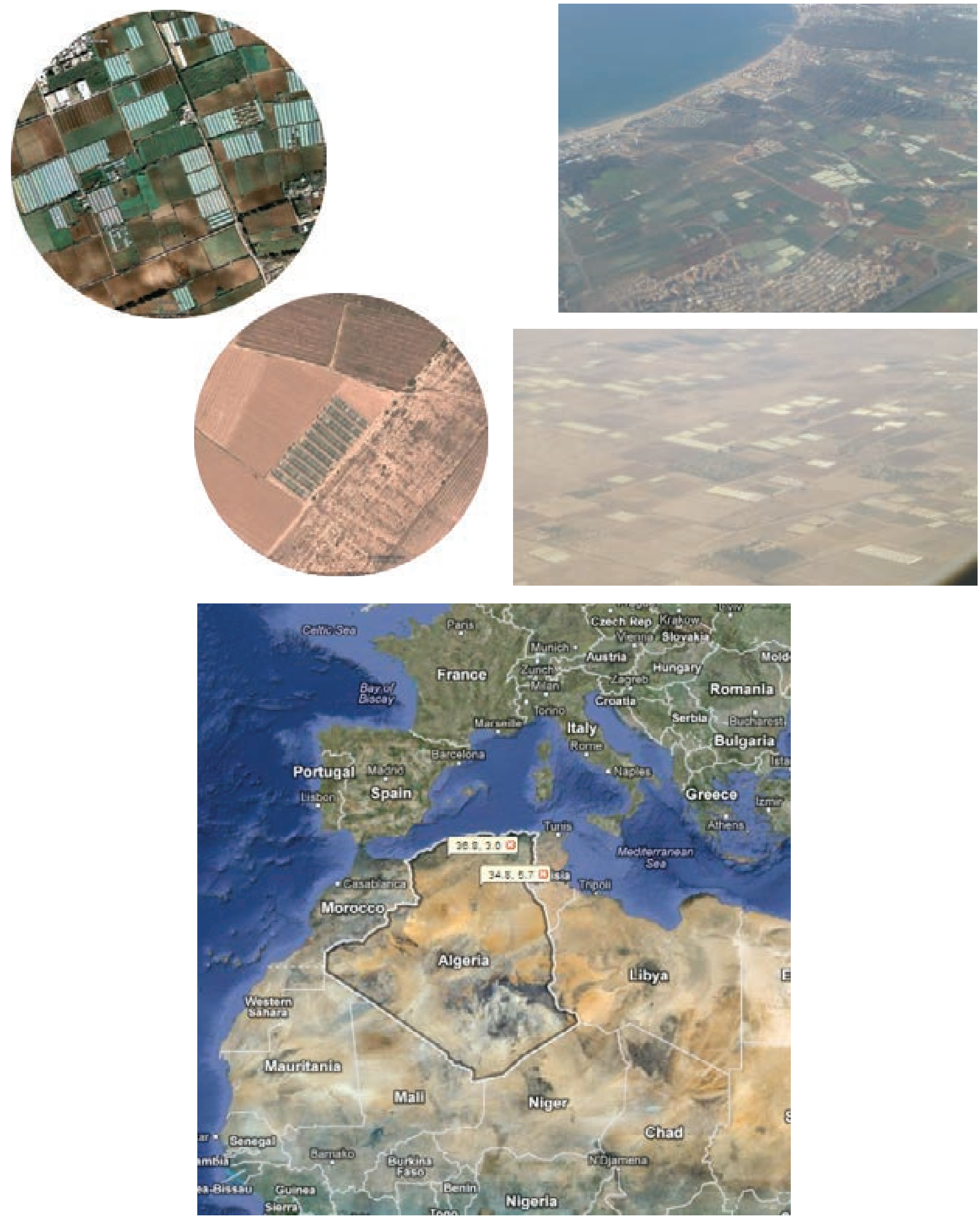


Figure 1.1. Location of the two greenhouse areas in Algeria; Algiers (Zeralda, upper two) and Biskra (lower two).

2 Methodology

This section elaborates on the methods that are used in this study. The design methodology for the greenhouse is explained, followed by some background on the simulation models used to simulate the climate and crop production inside the greenhouse. The final section describes the methods of the economic analysis that will be performed.

2.1 Design methodology

Designing protected cultivation systems is a multi-factorial optimization problem. During the design process, choices have to be made with respect to construction, cladding material, climate conditioning equipment, energy sources, energy management, light management, growing substrates, water and nutrient supply, internal logistics and labour, to mention a few. All of these choices mutually influence each other and are influenced by local boundary conditions like climate, market, legislation and availability of resources, the degree of technology chosen. The choices made also strongly influence the economic result.

To push the multi-factorial design of protected cultivations systems, a general design method is used. It is based on systematic design procedures that have been described by for instance Van den Kroonenberg & Siers (1999) and Cross (2001). The design procedure roughly contains the following steps:

1. Definition of the design objective, (here: design of a vegetable greenhouse for Algeria);
2. In a brief of requirements the specifications and design objectives are stipulated (here: low energy input, use of sustainable energy, high water use efficiency, high production and product quality and predictability of production, high food safety by low pesticide use, high ratio of benefit and costs of the production system);
3. A systems analysis will reveal the functions needed;
4. Derivation of alternative working principles for each function which yields a so-called morphological diagram. For example, in case of cooling we may consider natural ventilation, recirculation fans, fogging systems, pad-and-fan cooling or even air-conditioning systems with heat exchanger as design alternatives. Similar alternative working principles have to be described during this phase for the other functions;
5. Concept development stage. During this stage, the different functions, or more specifically working principles in the morphological diagram, are combined into a conceptual design that should at least satisfy the functional requirements stated in the design specifications. Several different concepts are designed at this stage;
6. Design evaluation and bottle-neck assessment. During this stage the various conceptual designs are evaluated in view of the design requirements stated above. Design evaluation is based on expert assessment and on quantitative simulation using mathematical models (here: dynamic greenhouse climate models and an economic models);
7. For the conceptual design(s) chosen, each working principle has to be worked out in more detail. For example greenhouse climate set points and cropping strategies; not part of this study;
8. The design prototype is built and tested in view of the design requirements.

The advantages of such a design procedure can be summarized as follows. It prevents jumping too quickly to a solution while not having looked into the overall design problem seriously. It prevents trial and error. It produces a good overview of the design requirements and reduces the chance of overlooking some essential design requirements. Bottle-necks and design contradictions are identified at an early stage. It offers insight into design alternatives and economical perspectives. It offers a basis for sound and objective decisions during the design procedure. By producing insight, stake-holders and decision makers can contribute to the process and are more easily convinced of the correctness of the design. Clearly, such a design method guides the engineer in the design process, but it does not guarantee success. In depth assessment of promising concepts with adequate models (here greenhouse climate, crop and economic models) and decision support systems helps to increase the success rate.

2.2 Description dynamic climate model KASPRO and input data

For the evaluation of various designs of greenhouse systems, several decision support systems have been developed such as KASPRO (de Zwart 1996),SERRISTE in France (Tchamitchian, Martin-Clouaire *et al.* 2006) or HORTEX (Rath 1992) or GTa-Tools (Van 't Ooster, Heuvelink *et al.* 2006). These systems support either designers or growers with reliable and quick assessment of energetic effects and crop responses of both the strategic and the operational choices.
In this study the KASPRO model is used. This extensive dynamic simulation model simulates a full-scale virtual greenhouse based on the greenhouse construction elements, ventilation openings, greenhouse equipment, different covering materials and their properties (transmission, reflection, and emission), set points for inside climate and the outside climate of a given location. Any computed physical quantity can be listed as output, but for the current project the observed output comprises the realised greenhouse climate at every hour of the year, the energy consumption, the amount of water evaporated by the crop, the amount of CO_2 applied and the dry matter production of the crop.

The model is based on the computation of relevant heat and mass balances (Bot 1983). The heat balances describe both the convective and radiative processes. The mass balances are constituted from exchange processes through leakage and ventilation (Jong 1990). They include canopy transpiration (Stanghellini 1987) and condensation at cold surfaces. The mass balances around the CO_2-concentration are based on losses of CO_2 by ventilation and photosynthesis, and gains of CO_2 by dosing and respiration.
Basically, the model describes the entrance of solar radiation into a greenhouse structure and computes the heat and moisture fluxes induced from this radiation. The heat and moisture is released predominantly by the canopy, but the heat fluxes originate from other opaque elements in the envelope as well. Also, reflection of solar radiation, typically by the covering structure and by reflecting shading screens, is taken into account. The heat and moisture fluxes affect the air conditions around the canopy, which are in dynamic interaction with the greenhouse construction and the environment. To a certain extent, the interaction between the microclimate around the canopy and the environment can be controlled by means of heating, ventilation, humidification and dehumidification, CO_2 application, shading and optionally even by means of cooling.

Greenhouse climate is controlled by a replica of commercially available climate controllers. The total set of differential equations is solved numerically (De Zwart 1996).

For this project, the KASPRO simulation model was used to analyze the effect of local outside climate conditions on inside greenhouse climate and crop response with an assumed greenhouse configuration. The effect of cooling by natural ventilation or evaporative cooling by fogging was analyzed. The effect of CO_2-dosing was computed and light control by means of a shading screen or artificial lighting was studied.
Cooling by natural ventilation might not be enough in a subtropical climate with high temperatures and high irradiations. Providing low outside humidity conditions, evaporative cooling by fogging helps to improve the greenhouse indoor climate conditions on these days. The fogging capacity that has to be installed is dependent on the typical local outside climate conditions.
CO_2-dosing can increase the biomass production, but when the ventilation rates are high, large dosing capacities are required and do not contribute to sustainability since CO_2 is then released into the outside air.
In regions with radiation intensities as high as in Algeria, the contribution of the highest intensities to the production can be much less than the contribution of the moderate intensities. Therefore, it has to be investigated if the application of a shading screen could be favourable in order to avoid too high temperatures in the greenhouse, whereas the decrement of photosynthetic potential remains limited.
The following data were used as input on an hourly base: outside temperature, humidity, radiation, wind speed and sky temperature. KASPRO uses a photosynthesis model to estimate the growth and evapotranspiration of the crop. This approach works well to simulate the greenhouse climate, but is less suitable for an accurate prediction of the total yield. Therefore we have used an additional model to estimate the yearly yield of the crop. The model is developed by (Vanthoor) and uses a more detailed crop model that takes into account the adverse effects of extreme temperatures (both high and low). The result of the KASPRO simulations are the realized climate inside the multispan tunnels and the estimated

crop production on an hourly basis. Also, all other variables around the greenhouse may be exported, if applicable. These include energy consumption, amount of water transpired by the crop, the amount of CO_2 applied, etc.

2.3 Water streams model

The model WATER STREAMS estimates the ingoing and outgoing water flows at a commercial nursery during a year or a growing cycle of a crop. The model uses the transpiration model from de Graaf (1988) or Stanghellini (1996), parameters to simulate the water uptake for crop growth and is described in Voogt *et al.* (2012). Climate data such as temperature, the sum of radiation and precipitation as well as related greenhouse climate data are used as input. A number of parameters are used to calculate the various water fluxes on a daily base. The volume of the rain water collection is a fundamental parameter, because rainwater is used as the primary water source. The chosen year is a variable and can be characterized as a dry, a wet or a cold year (more variables available) following a real time dynamic year from last thirty years of the weather data from Naaldwijk (official KNMI weather station) but any other region can be implemented. The ten most important greenhouse crops can be chosen, amongst them tomato, sweet pepper, cucumber, rose and gerbera. For each crop some crop specific parameter values need to be chosen (day/night temperature, intensity and duration of artificial lighting, sodium threshold value and specific uptake). Other parameter values to be chosen are: sources of additional water with their sodium concentration, the drain fraction, fraction of leakage and filter cleaning water, system values, etc.). As a result of the mentioned input data the model WATERSTREAMS calculates per day the amount of used rainwater, additional water and condensation water. Further the crop uptake, the required amount of discharge of the nutrient solution, resulting from sodium accumulation above the threshold value and amounts of leakage and filter cleaning water are calculated. Results are presented in tables and graphs. Besides the emission of water with nutrients caused by high sodium levels, the emission of N and P and other elements can be estimated. As all parameters can be easily changed the model can be adapted to specific situations. For this study climate data were used from Algiers and Biskra.

2.4 Description of economic model and data collection

In the economic model several scenarios concerning different degrees of technology are analyzed to find the optimum greenhouse design for vegetable production in Algeria.

The economic model is based on the systematic calculation method given by KWIN (2010). Benefits and costs are calculated on a yearly base. On one side the yield and product price are calculated as benefits, on the other side costs of heat and electricity, plant material, labour costs, costs for crop protection, crop nutrition, water, substrate, plastic films, wires, clips and packaging with related cost prices are calculated as variable costs. Next to that the initial investments for installations like greenhouse construction, covering material, screening, insect netting, heating and cropping system, irrigation system, CO_2 dosing, fogging, climate control and general costs for supervision, transport, packaging area and machinery are calculated per scenario. Initial investments are calculated back to annual costs by taking into account depreciation, maintenance and interest. The balance of benefits and total costs results in the net result. Besides, the payback period is calculated by the total investment sum divided by the cash flow (net profit + depreciations) . After all a sensitivity analysis is done with which the effect of variations of product price and investments is calculated on the payback period.

Several input data for the cost-benefit analysis are given by the model calculations. The virtual greenhouse model KASPRO gives data for the tomato yield in terms of dry matter production, heat, electricity, CO_2 and water consumption, which are used as input data for the economic model. The amount of plant material is assumed to be 2 plants per m^2. The costs for crop protection, crop nutrition, substrate, plastic film, wires and clips are taken from KWIN (2010) and are adapted to the Algerian situation based on Amrar (2012). For all scenarios the labour costs are assumed to vary in proportion to the yield. It is not considered that the labour costs are higher in the traditional Algerian situation due more manual work instead of the use of machinery. An open irrigation system is assumed to consume 40% more water than a closed irrigation system. The costs for packaging are assumed to vary with yield. Prices for energy (diesel) and electricity and labour are given by local information and Amrar (2012). Depreciation is assumed to be 3 years for plastic film covering material, insect netting, screening and CO_2 system. For most other installations it is assumed to be 15 years. Maintenance costs are between 2% and 8%, depending on the equipment (KWIN, 2010). Actual interest rates in Algeria are 6.5% (source: Trading Economics). The seasonal tomato producers prices were not available and therefore the tomato price is estimated at 70% of the wholesale prices (DSA, 2012) and specified for the two regions based on the harvesting period (Algiers: average price 40 DA/kg; Biskra: average price 41.5 DA/kg). For all economic calculations a company size of minimum 2 ha is assumed. The total investment of the company is taken into account incl. general facilities and packaging area. An overview of assumptions of prices, costs and benefits are given in Table 2.1, assumptions considering investments, depreciation, maintenance and interest rates and the resulting annual costs of investments are given in Table 2.2.

2.4.1 Electricity and diesel prices

Energy prices in Algeria are at a low level, because the government subsidises it.
According to [https://energypedia.info/index.php/Algeria_Energy_Situation] the electricity price is: 0.04583 €/kWh or 4,1789 DZD/kWh. Based on information during the visit an electricity price is assumed of 3 DA/kWh. Diesel prices are estimated at 30 DA/liter and are based on information during the study visit.

Table 2.1. Assumptions of prices, costs and benefits for the economic model (reference production system).

	Price [DZD]	*Source of information*
Price for truss tomatoes [DZD/kg]	40 (Algiers); 41.5 (Biskra)	DSA, 2012; processed by LEI
Diesel [DZD/liter]	30	Info from visit
Electricity [DZD/kWh]	3	Info from visit
Ground water [DZD/m^3] (plant feed water)	.	
Plant material [DZD/plant]	9.5	Estimate on Amrar, 2012 and KWIN, 2010
Labor costs crop [DZD/h]	87.5	Amrar, 2012 and ITCMI, 2012
Crop protection [DZD/m^2]	75	Estimate based on KWIN, 2010 and Amrar, 2012
Crop nutrition closed cycle [DZD/m^2]	75	Estimate based on KWIN, 2010 and Amrar, 2012
Crop nutrition open system [DZD/m^2]	105	Estimate based on KWIN, 2010 and Amrar, 2012
Substrate [DZD/m^2]	100	Estimate based on KWIN, 2010 and Amrar, 2012
Plastic film, wires, clips [DZD/m^2]	50	Estimate based on KWIN, 2010 and Amrar, 2012
Packaging [DZD/kg]	0.5	Estimate based on KWIN, 2010 and Amrar, 2012

Table 2.2. Assumptions of investments, depreciation, maintenance and interest for economic model. Investment cost are taken from quotes given by industrial partners.

all investments are per m2 greenhouse ground area	investment [DZD/m2]	depreciation [%/year]	maintenance [%/year]	annual costs investments [DZD/m^2/ year]
Plastic multispan tunnel, excl. cover	2520	7	2	264.60
Plastic cover for multispan tunnel	180	30	2	60.30
Plastic single tunnel, excl. cover	700	7	2	73.50
Plastic cover for single tunnel	180	30	2	60.30
Heating system	1125	7	2	118.10
Pad and fan system	1200	25	2	342.00
Cropping system	330	7	2	34.65
Insect netting	400	20	5	106.00
CO_2 dosing	70	25	5	22.05
Irrigation system open	440	15	5	94.60
Electra installation	280	7	2	29.40
Climate computer	235	20	8	35.63
Other: transport, packaging area, trolleys and machinery	345	7	2	36.20

3 Climate data

This chapter summarizes the main climate characteristics relevant to greenhouse design for the area of Algiers and Biskra.

The optimum design for a greenhouse design is strongly influenced by the local climatic conditions. The day length in Algeria is more constant throughout the year than in the Netherlands. The shortest day in winter is just less than 10 hours; the longest day is just over 14 hours (Figure 3.1.).

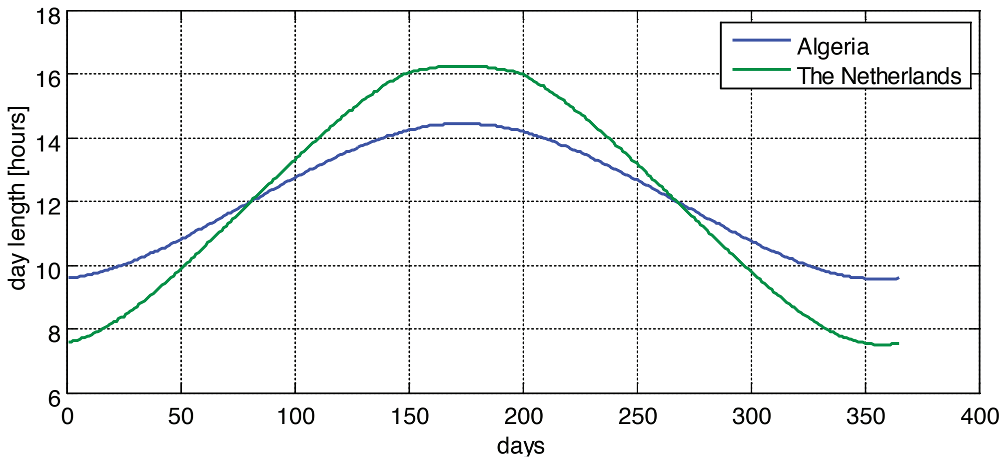


Figure 3.1. The course of day length in Algeria and in the Netherlands.

3.1 Radiation

Weather data for two places in Algeria are available on an hourly basis; Algiers and Biskra. The global radiation is measured, however there are no separate data for direct and diffuse radiation. By using the data for cloudiness it is possible to construct the radiation data reasonably accurately. Based on the latitude of both cities (36.7°N and 34.8°N), the course of the intensity of radiation on any clear day is computed and combined with the observed cloudiness to compute global, diffuse and direct radiation profiles.

The total yearly radiation varies slightly over the years. Figure 3.2. shows radiation data for the years 2005 - 2011 for both Algiers and Biskra. Data for The Netherlands (2011) are also included (gray line) as a reference.
Radiation sums are different for both locations; Biskra receives 10 to 15% more radiation than the coastal zone where Algiers is located. As potential plant growth is mainly depending on the total light sum, the potential yield will be higher in Biskra than in Algiers (provided that the indoor climate is not too warm).

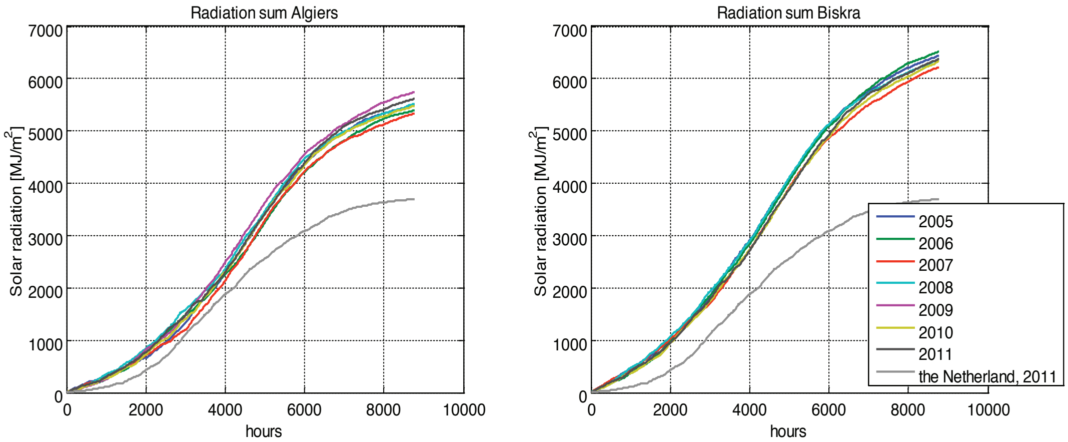


Figure 3.2 Cumulative radiation sums for global radiation in Algiers (left) and Briskra (right) for the past 7 years. For reference purposes, the radiation in the Netherlands is included.

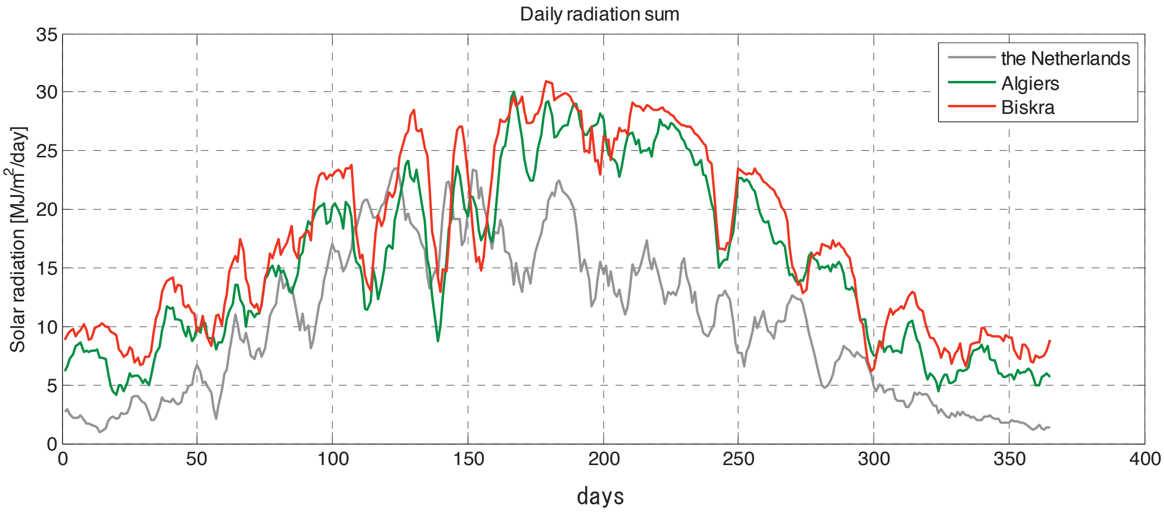


Figure 3.3. Daily radiation in Algiers and Biskra and the Netherlands in 2011. The data were smoothed by a 7 days moving average filter.

Figure 3.3. shows the daily sum of radiation at the two locations in Algeria and in The Netherlands for 2011. Algeria has a higher total solar radiation than the Netherlands. Moreover, the radiation levels are more constant over the year. Because of these two facts, potential yield for vegetable production in Algeria is higher than in the Netherlands. However, due to the higher radiation intensities in Algeria, higher greenhouse temperatures are to be expected, especially because the mean outside temperatures are higher as well. These outside temperatures are shown in the following section.

3.2 Temperature and humidity

The daily average temperature in Algiers varies between 10 °C in winter and over 25 °C in summer. In summer, the maximum daily temperature can exceed 40 °C, and the minimum temperature in winter is lower than 5 °C.
The climate in Biskra is warmer; many summer days have a mean temperature well over 30 °C, and maximum temperatures often exceed 45 °C (Figure 3.4.). In winter, temperatures in Biskra fluctuate between 10 and 15 °C, with extremes as low as 5 °C.

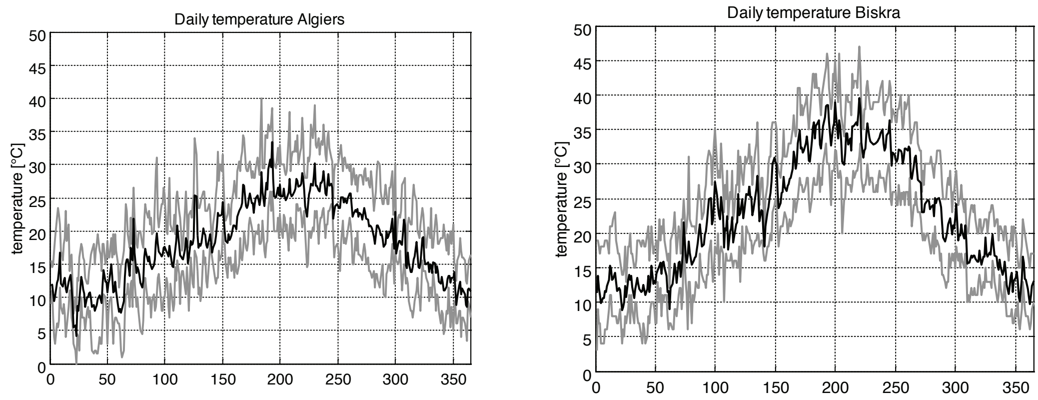


Figure 3.4. Daily mean (black line) outside temperature in Algiers and Biskra in 2011. The two gray lines give the daily minimum and maximum values.

The relative humidity of the air in the Algiers area is much higher than in Biskra (Figure 3.65.)

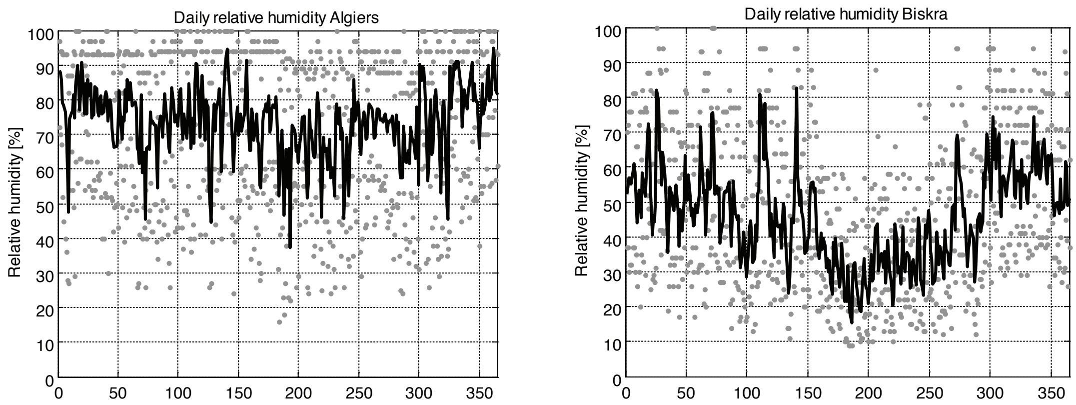


Figure 3.5. Daily mean (black line) outside relative humidity in Algiers and Biskra in 2011. The gray dots give the daily minimum and maximum values.

3.3 Wind

3.3.1 Wind speed

The ventilation rate of a naturally ventilated greenhouse is linear with the wind speed (Parra, 2004). Therefore, it is important to know the local wind conditions to make a good greenhouse design. Figure 3.6. shows the daily average wind velocity in Algiers and Biskra in 2011. The maximum and minimum speed are given by the thin gray dots.

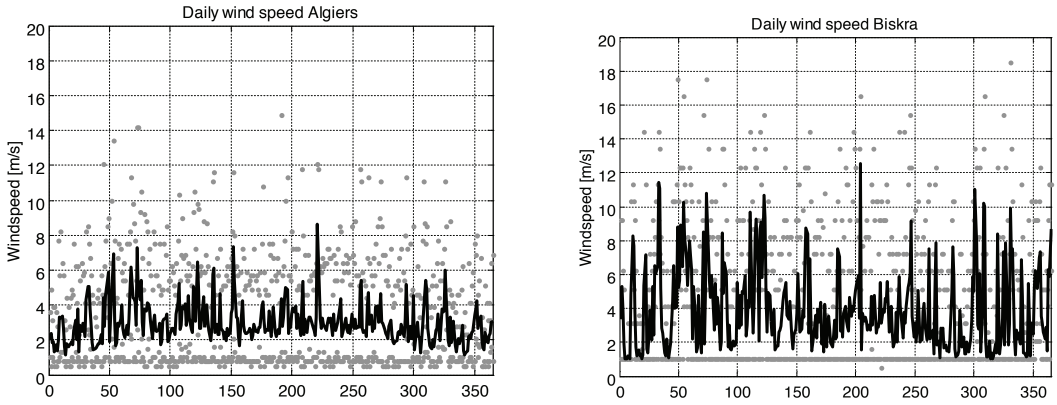


Figure 3.6. Wind velocity in Algiers and Biskra, 2011 (black line is average, grey dots are the minimum and maximum values for each day).

Apart from the daily average wind velocity, the wind speed pattern over the day is important for the ventilation rate of the greenhouse. In Algiers, wind speeds are high in the middle of the day, and very low at night (Figure 3.7.). Thus, ventilation rates at night will be considerably lower than during the day. In Biskra, the pattern is not as strong as in Algiers, with wind speeds only slightly higher during the day (Figure 3.8.). The high peaques in Biskra are of importance for building greenhouses strong enough.

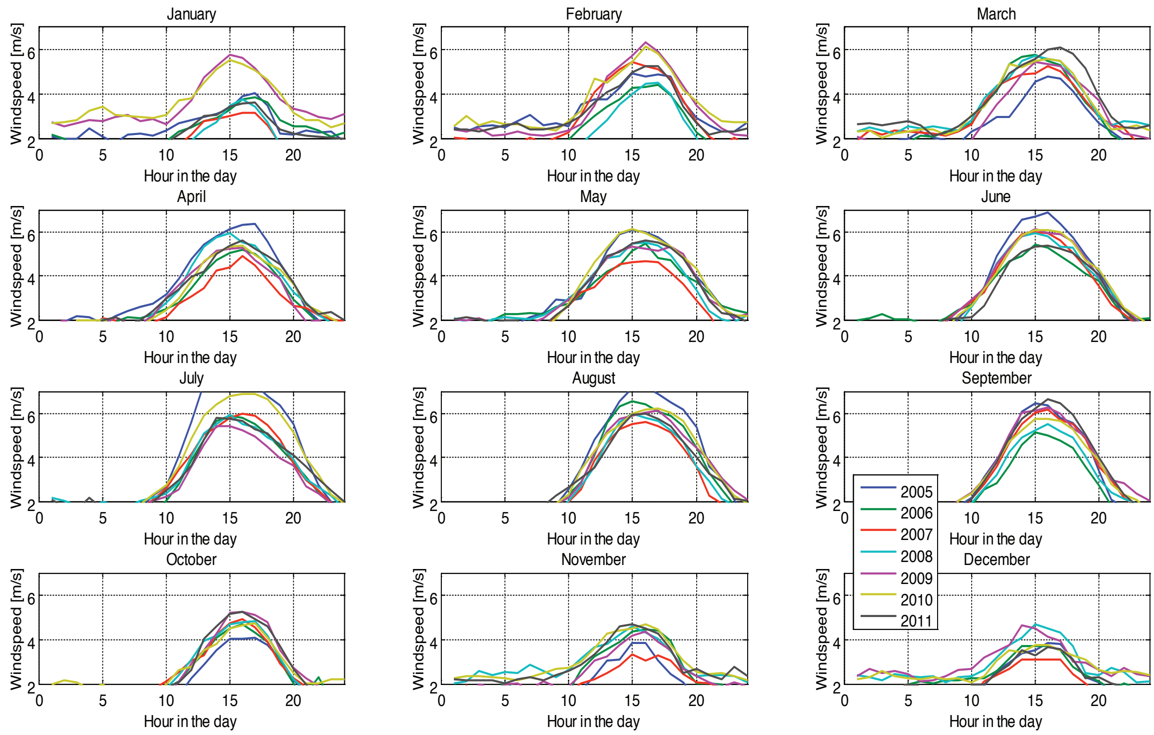


Figure 3.7. Cyclic mean for wind velocity for all 12 months in Algiers. The lines represent the average daily values for each month.

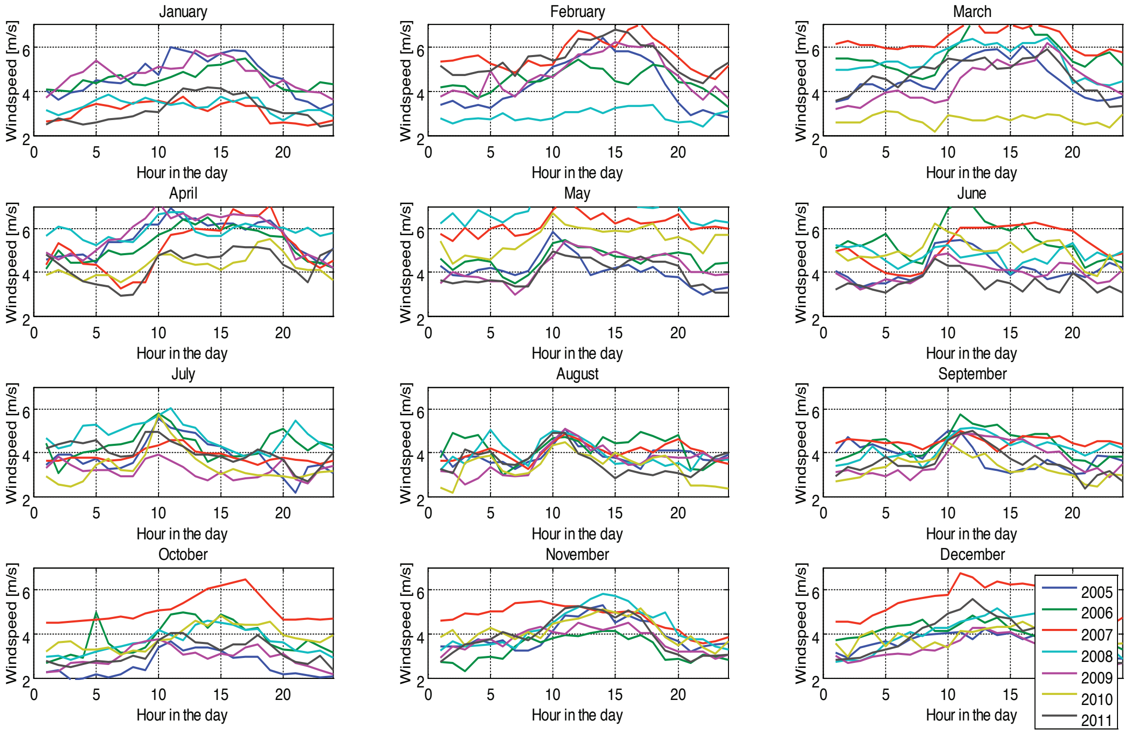


Figure 3.8. Cyclic mean for wind velocity for all 12 months in Biskra. The lines represent the average daily values for each month.

3.3.2 Wind direction

Like the wind speed, the wind direction has a large influence on the ventilation rate. Especially for the tunnel greenhouses that have only one opening at each end, it is beneficial to place the greenhouses such that they are parallel to the prevailing wind direction.

Figure 3.9. shows the prevailing wind direction in Biskra. The wind predominantly blows from the North-West (310-360°) and the South-East (100-130°). Looking to Google maps it appears that the predominant position of the greenhouses in the Biskra area is East-West. Construction of greenhouses more according the north west - south east direction increase the ventilation rate and, consequently, lowers the temperature in the greenhouse. In Algiers there is not such a dominant wind direction (Figuur 3.10.).

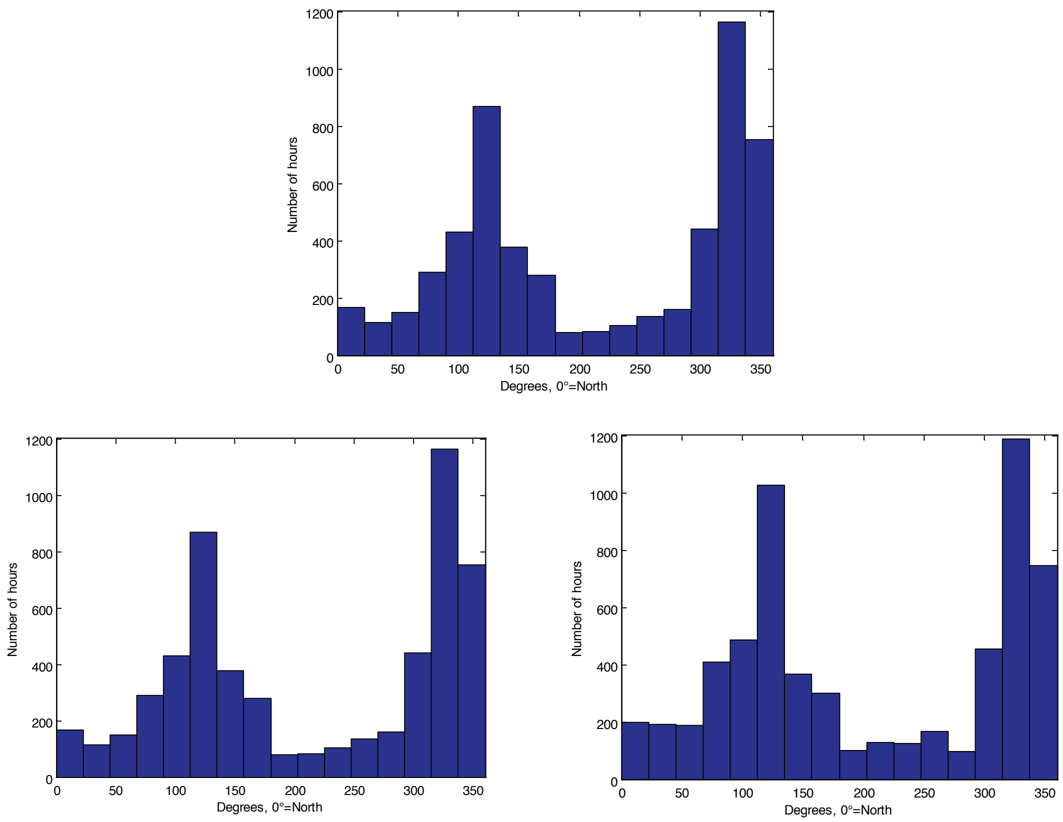


Figure 3.9. Wind direction in Biskra; daily values for each month for the years 2005 (top), 2007 (left) and 2008 (right). 0=North, 90=East.

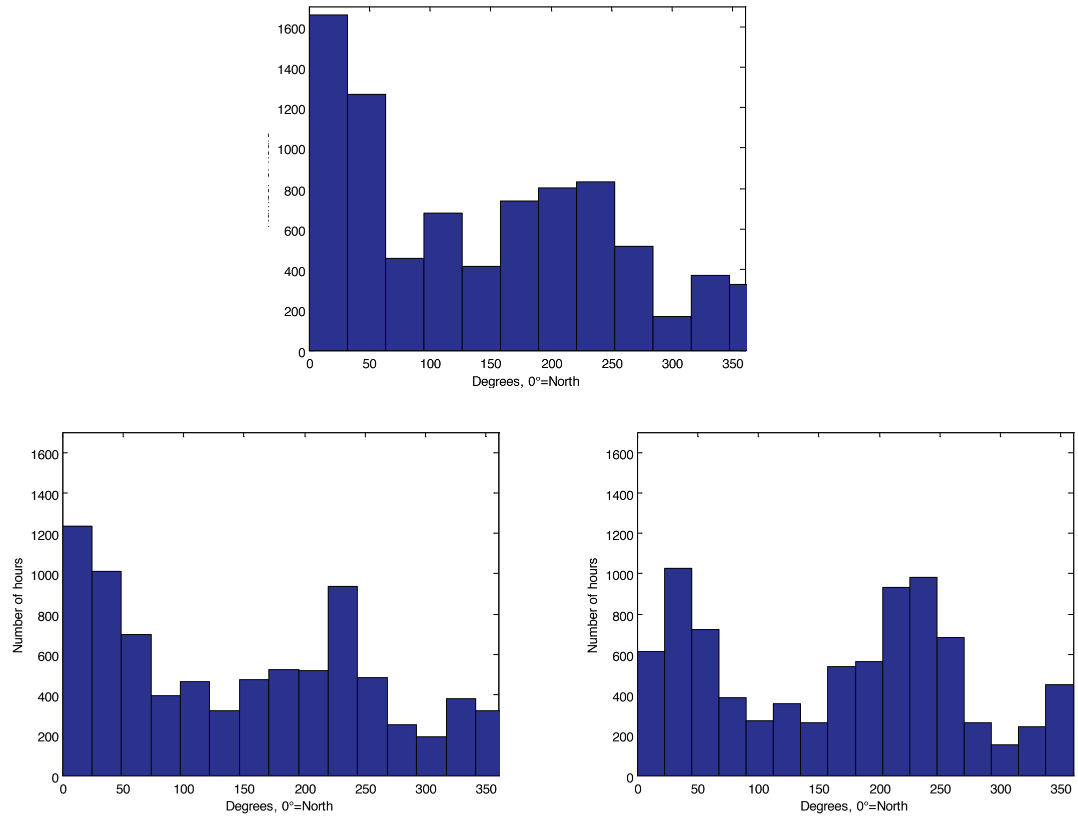


Figure 3.10. Wind direction in Algiers; daily values for each month for the years 2006 (top), 2008 (left) and 2010 (right) 0=North, 90=East.

3.4 Precipitation

Precipitation data are scarcely available. In this study, we used data from the European Climate Assessment and Dataset, which is a collection of climate data (T, precipitation) from many sources and which are available online at http://eca.knmi.nl/. In Algeria, these data are available for five locations (Figure 3.11.). As we focus in this study to the areas of Algiers and Biskra, the ECA data are very useful for the Algiers area. For the Biskra area, no reliable data are available.

Figure 3.11. Locations of the available precipitation measurements in Algeria.

Figure 3.12. shows the ECA precipitation data at four locations in Algeria. The amount of precipitation at the coast (Algiers) is higher than in the rest of the country, averaging around 550 mm/year in the last decades.

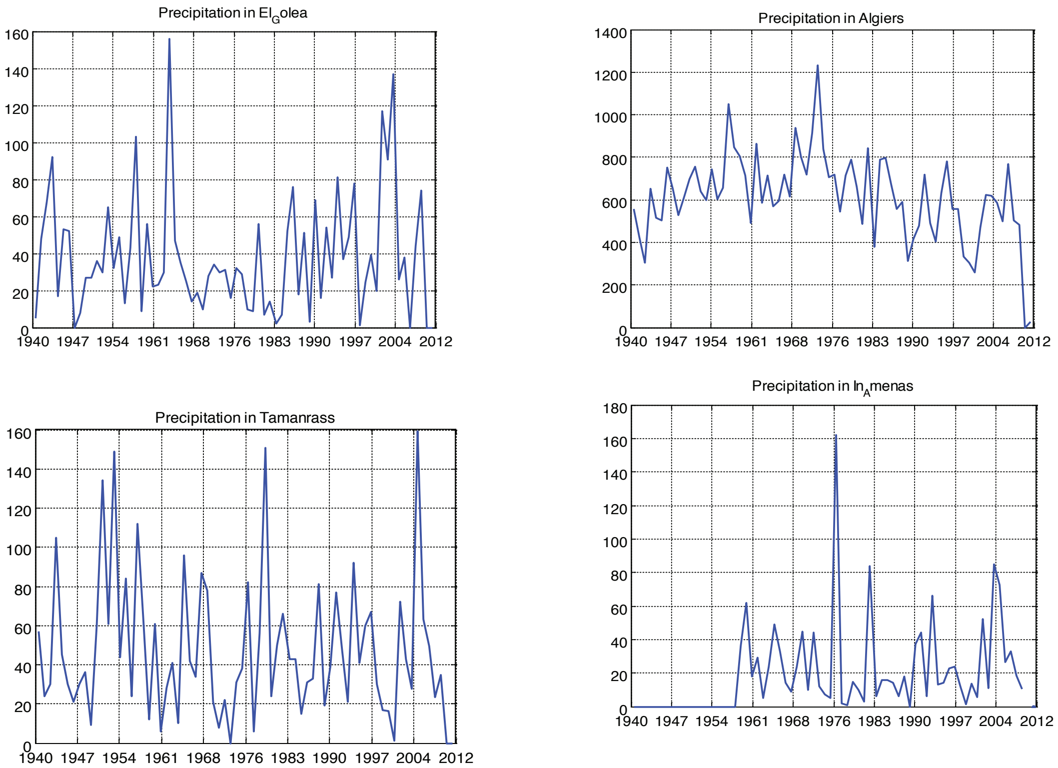


Figure 3.12. ECA available precipitation measurements of Algeria at four locations.

3.5 Conclusions climate data

From the available climate data, we made the following conclusions:

- The yearly solar radiation sum is around 6.5 GJ/m^2/year in Algiers and around 7.2 GJ/m^2/year in Biskra. This is much higher than in The Netherlands (3.8 GJ/m^2/year). Therefore the *potential* for plant growth is much higher (more radiation = more photosynthesis) in Algiers. Obviously, other climate factors (temperature, humidity) have to be controlled to be able to benefit from the high radiation.
- Both in Algiers and Biskra the minimum temperatures are under 10 °C in winter. This is quite cold for plant production, so the use of a heating system should be considered for use even below 15 °C.
- Summer temperatures are high, especially in Biskra (maximum temperatures often exceed 45 °C). In these circumstances, year round production is hard to realize.
- The relative humidity in Biskra is low, which makes it possible to cool a greenhouse with evaporative cooling. In Algiers, the humidity is higher and therefore the cooling potential is less.
- At both locations, wind speed during the day is normally over 2 m/s, which should be enough for naturally ventilated greenhouses.
- Precipitation is scarce, especially in Biskra (though we do not have exact figures estimated at 200 mm). With an average precipitation of 550 mm/year in Algiers, it is possible to collect and store rainwater for irrigation.

4 Single span tunnels

This chapter describes various improvements that can be made to the single span tunnels. Most improvements we suggest here are (very) low cost, which is in line with the low investment cost for the tunnels themselves.

4.1 Simulation settings

The climate inside a tunnel is simulated with KASPRO. Originally, KASPRO is intended for large, multi span greenhouses. The model inputs are adjusted such that the model give credible estimates for the climate inside the tunnels. Unfortunately, no measured data are available for calibration of the model. Therefore, the simulation data can only be used to compare the effects of the different measures. For example, the effect of shading on the climate can be studied between different shading levels. However, the results should not be compared with the simulation results for multi-span greenhouses.

Settings used based on Algerian practice:

- Tunnel dimensions: 8x50x3.2m high
- The air content is approximately: $20m^2$ x 50m = $1000m^3$ (=$2.5m^3/m^2$). The size of the opening at the beginning and end of the tunnel varies in practice; we will use $8m^2$ in our simulations. Some tunnels have additional openings in the roof, spread over the length of the tunnel. The effect of these openings cannot be studied with KASPRO, but are studied with a CFD model instead.
- Ground surface: 8*50 = $400m^2$
- The window fraction is $16m^2$ window/$400m^2$ greenhouse = 0.04.
- No heating system
- Planting date: 15th of September. End of season: 1st of May for Biskra and 1st of June for Algiers.

The model assumes that the windows are closed if the temperature inside is too low.

4.2 Optimal ventilation capacity

Effect of window ratio on ventilation rate and temperature

Increasing the size of the area of window openings in the tunnel does have a positive effect on the number of very hot hours in a year. The Figure 4.1 shows a duration load curve for the current situation (green line) of a tunnel with only openings in the two side walls. The other lines show that if the window fraction is increased, the temperature inside the greenhouse approaches the temperature outside. Please note that the figures show the simulations for a growing season of 1st of September till the 1st of May.

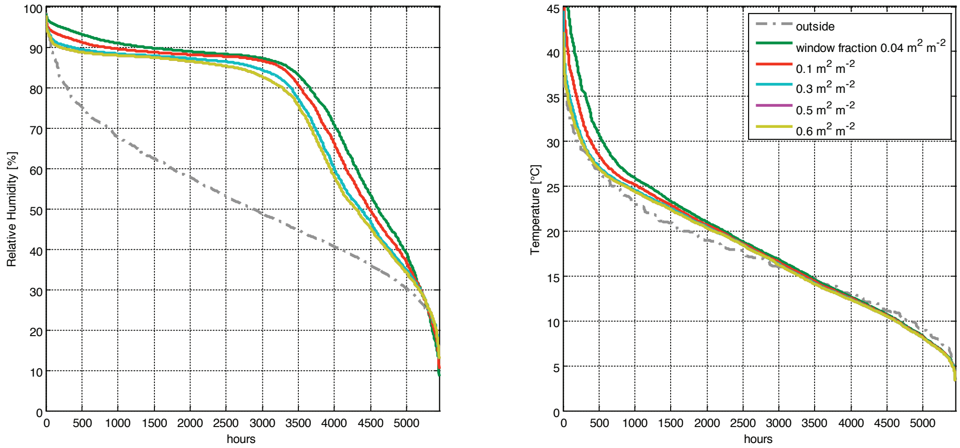


Figure 4.1. Effect of various window sizes on the climate (temperature, RH) inside a single span tunnel located in Biskra (2011 climate data).

4.3 Shape and position of the windows

The size of the ventilation openings does have a large effect on the climate inside the tunnel. The tunnels currently used in the region mostly have only openings at the front and rear end. The surface of these openings is very limited; in the order of 0.03 m^2 opening / m^2 greenhouse area. (figure 4.2)

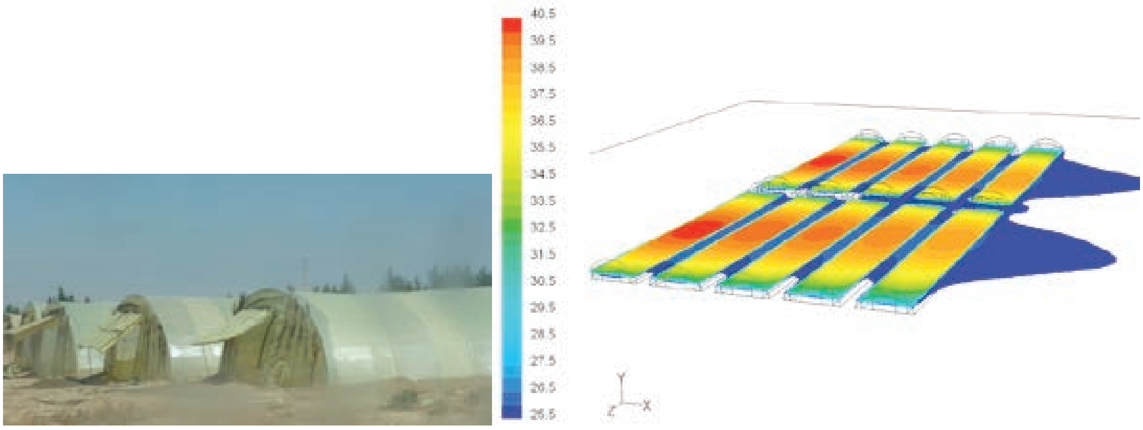


Figure 4.2. CFD calculation of the current tunnels with window fraction of 3%

This small window ratio could be increased by making openings in the sides of the tunnels. in practice this is sometimes done by separating the sheets of plastic film at the edges, resulting in oval holes in the sides every 4 meters. Unfortunately, the size of these holes cannot be large and the corresponding window fraction is in the order of 5% (Figure 4.3.). At an ambient temperature of 25 °C, the indoor temperature inside is not much better than in the greenhouse with only openings at the front and back.

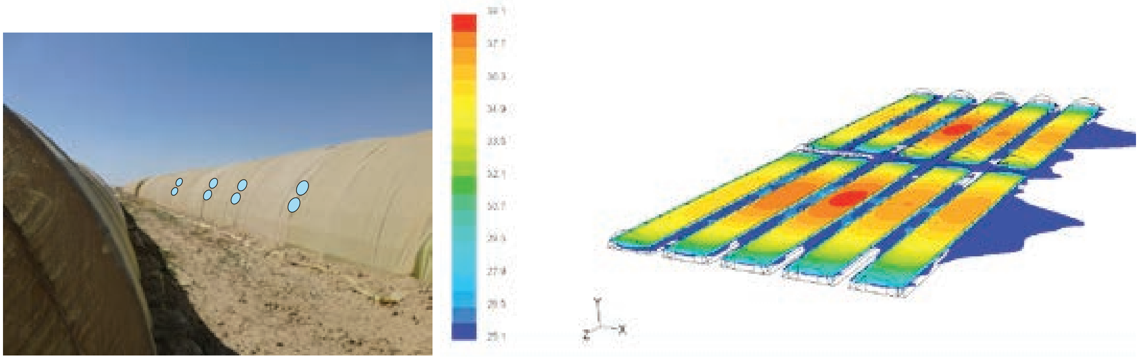


Figure 4.3. CFD calculation of the current tunnels with small holes, resulting in a window fraction of 5%

To bring the temperature in the greenhouse closer to the ambient temperature, larger openings in the greenhouse are needed. A tunnel with a window fraction of 30% has a much better indoor climate; the temperature is around 30 °C (at ambient of 25 °C). This is very beneficial for the plants, at times that the ambient temperature is high (Figure 4.4). When it is cold outside, the large window opening must be closed to prevent damage to the plants. Therefore, if large openings are created in the greenhouse cover, they must be made movable.

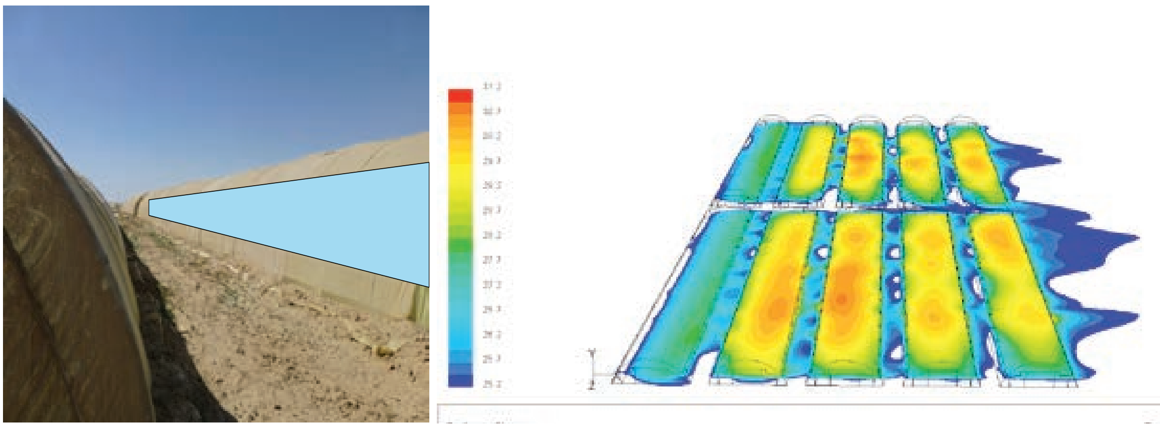


Figure 4.4. CFD calculation of the current tunnels with large side windows, resulting in a window fraction of 30%

Conclusion ventilation and tunnel shape

Larger windows do decrease the temperature inside during the hottest hours of the growing season. The opening size should be in the order of 30%. This is very beneficial for the crop, resulting in a potential crop production increase of 50%.

4.4 Cover: different types of plastic film

In vegetable production, a rule of thumb states that *1% more light = 1% more potential production.* Of course this rule is only valid if all other growth factors (T, RH, CO_2, etc) are not limiting and within the optimal ranges. However it is save to state that a greenhouse covering should allow the sunlight to enter the greenhouse as much as possible for a maximum potential production rate.

Some background information on covering materials

A glass cover has a higher transparency than a plastic cover over the years as the light transmission of plastics decreases due to ageing. Also, a glass cover can be cleaned easily as opposed to plastics, a property which is important to keep the light transmittance high. However, glass is expensive and nowadays, cheap, reasonable good plastics are available. Moreover, plastic covers can be made of modified plastics that give the cover special thermal properties. For example, plastic films exist that reflect or absorb the near infra red (NIR) radiation. In this way, less heat radiation enters the

greenhouse, which could result in lower indoor temperatures (unfortunately this principle only works if a large fraction of the NIR is rejected, so materials need to be improved further before practical applications are possible).
Also, plastic films are available with a high IR transmission, which allows heat radiation to leave the greenhouse and therefore lead to lower air and crop temperatures. This is called a *non-thermic film*, as heat is not trapped inside the greenhouse, which is favorable in tropical areas (Hemming *et al.* 2006).
Table 4.1. gives some properties of four covering materials that are simulated. Three different types of plastic films were simulated with increasing infrared transmission.

Table 4.1. Properties of the plastic cover types that are compared in the simulations.

Material	EVA	EVA	PE	PE	glass
Thermic	yes	no	no	no	Yes
Diffuse	diffuse	clear	diffuse	clear	Clear
ID code	*PT02A*	*PT02C*	*PH03A*	*PK02E*	*Glass*
PAR transmission (perpendicular)	0.825	0.9064	0.893	0.89	0.90
diffuse transmission	0.7099	0.8092	0.765	0.8	0.83
Infrared transmission	*0.20*	*0.3905*	*0.37*	*0.54*	0
Infrared emission up	0.77	0.58	0.60	0.43	0.80
Haze	High	low	high	low	Low

The different cover materials result in different climates inside the greenhouse, especially at high and low temperatures. Also, the amount of PAR radiation inside the greenhouse differs, which has an impact on potential crop production. The results of our simulations with the different cover materials are shown in table 4.2. In the simulations, we have not used a shading screen to compare only the effect of different cover materials. In practice a shading screen will be used to reduce the number of very hot hours.

Please note that in these simulations the effect of haze is not simulated. In practice, a cover with high haze gives a higher crop production, especially in climates with high direct solar radiation, due to two main reasons:

1. Crop temperatures are lower in comparison to a non-haze cover because no direct light falls on the leaves
2. Scattered light is favorable for crop production because more lights reaches the lower leaves of the crop (Dueck *et al.* 2009).

The air and crop temperature is lowest in a greenhouse covered by a non-thermic plastic film. The downside of this is the larger number of cold hours in winter. In a greenhouse covered with clear glass, the temperatures of the crop gets very high, which is not favorable for the production.

The locally produced plastics perform quite well. The light transmittance is not high, especially the yellow plastic film has a low transparency. This causes some production loss. Also, the yellow film blocks UV light. This has a positive effect on the spread of pests such as whitefly and Bemisia tabaci, which are highly affected. No research has been done on the effect of UV blocking films on Tuta absoluta (though it is expected that Tuta absoluta is not stopped by a UV blocking film).

Conclusion greenhouse cover material
We advise to use a plastic film that is *diffuse* and has a *high transmission of light.* If the film is used on a single tunnel with large windows, it should be thermic (to keep the heat in the greenhouse in winter). If the tunnel has limited ventilation, a non-thermic film is probably better as this gives somewhat lower crop temperatures. In this case, an energy screen could be used to keep the greenhouse warmer at night.

Table 4.2. Performance of several cover materials with respect to temperature and potential crop yield (no shading used).

	transm. [%]	Tair>30 [hours]	Tcrop>30 [hours]	T<10 [hours]	yield [%]
Algiers					
Glass	73	139[1]	281	1166[3]	100
pt02a	65	111	178	1187	94
pt02c	72	106	120	1227	102
ph03a	71	106	125	1221	101
pk02e	70	95	59	1264	102
local, white	69	104	105	1236	100
local, yellow	64	97	78	1252	94
Biskra					
Glass	73	475[2]	453	823[4]	100
pt02a	65	449	339	899	92
pt02c	71	421	270	1170	96
ph03a	70	422	273	1147	95
pk02e	70	401	204	1346	92
local, white	69	416	257	1169	93
local, yellow	64	410	240	1179	88

[1] Algiers has 50 hours in the growing season with ambient temperatures over 30 °C
[2] Biskra has 408 hours in the growing season with ambient temperatures over 30 °C
[3] Algiers has 1114 hours per year with ambient temperatures under 10 °C
[4] Biskra has 600 hours per year with ambient temperatures under 10 °C

4.5 Evaporative cooling

The hot and dry climate in Biskra is perfect for an adiabatic cooling system. A cooling system with large capacity (600 gram of evaporation /m^2/h) in combination with large window fraction (30%) can keep the greenhouse temperature under 35 °C at all hours during the growing season (1 sept - 1 May). Moreover, the temperatures inside the greenhouse are considerably lower than outside during the hottest hours (compare the blue line to the dotted gray line in the Figure 4.5.). The cooling comes at the cost of water evaporation. In this simulations, 280 liters of water are evaporated to cool the greenhouse (per m^2 greenhouse). Because the the plant evapotranspiration is somewhat lower in a greenhouse with evaporative cooling system (600 l/m^2 versus 550l/m^2), the total additional water consumption by pad&fan system is 230 liters/m^2 (without taking into account flushing and cleaning of the system).

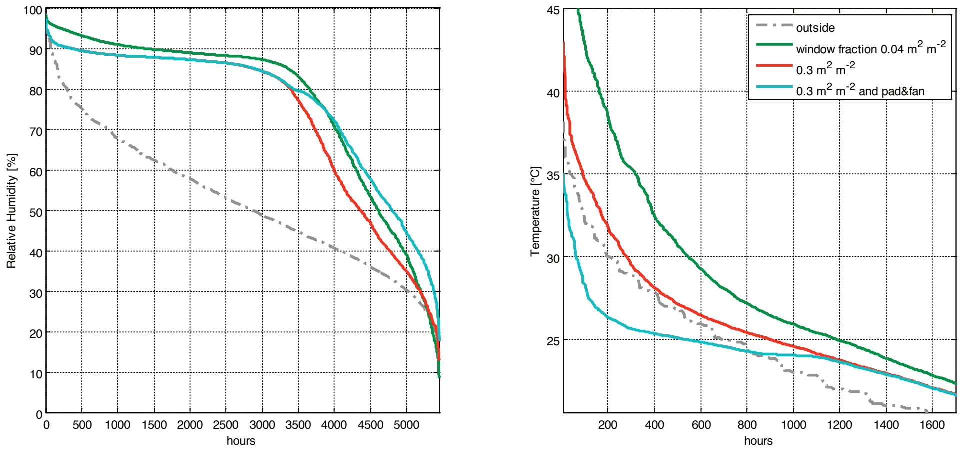


Figure 4.5. Effect of an evaporative cooling system in Biskra (2011 climate data, growing season 1 Sept - 1 May). The green line gives the climate in the current tunnels, the red line an uncooled greenhouse with large windows and the blue line shows the situation with evaporative cooling and large windows.

For Algiers, the situation in different. Here, the climate is more humid, which makes evaporative cooling less effective. Still, a cooling system helps to keep the temperatures in the greenhouse low during the hottest parts of the day (Figuur 4.6.). Evaporative cooling can keep the greenhouse temperatures lower than 30 °C during the whole growing season (1 Sept-1 June). The water use is 175 l/m^2, and the plant transpiration is 510 l/m^2. In Figuur 4.7. a detailed September week is given to show the difference to be achieved: about 10 °C lower temperature after evaporative cooling.

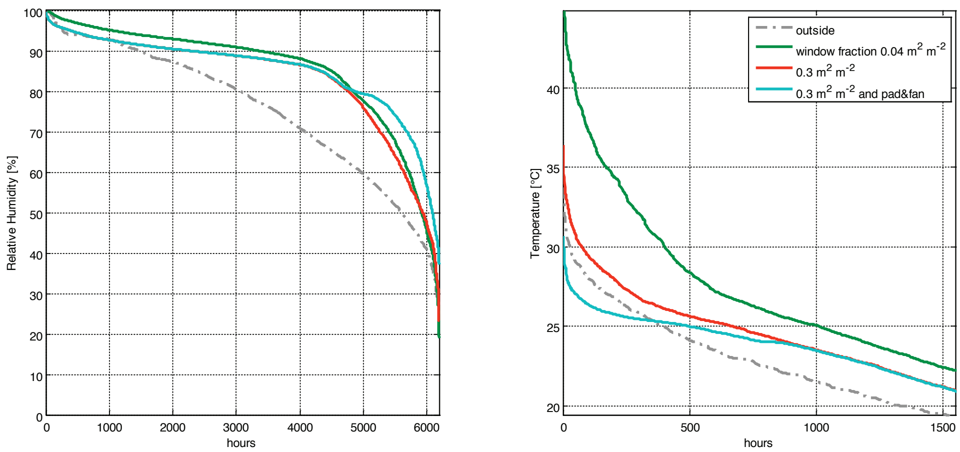


Figure 4.6. Effect of an evaporative cooling system in Algiers (2011 climate data). The green line gives the climate in the current tunnels, the blue line the situation with evaporative cooling.

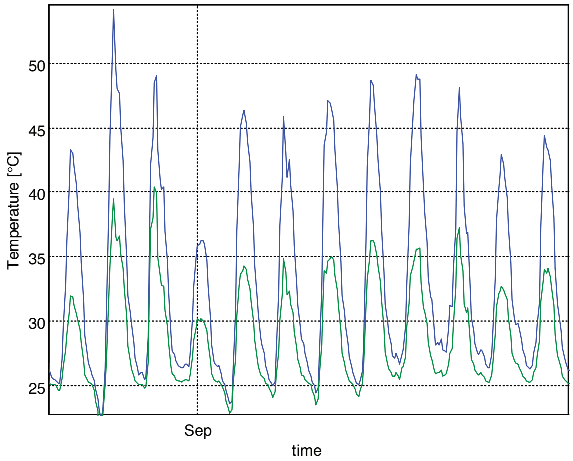


Figure 4.7. Illustration of the effect of an evaporative cooling system on the temperature in the greenhouse. During the hottest hours of the day, the cooling system can reduce the temperature inside by over 10 °C. The blue line shows the reference, the green line shows a greenhouse with large windows and evaporative cooling system (data for beginning of September 2011, Algiers).

Conclusion adiabatic cooling

Both in Biskra as well as in Algiers, pad and fan cooling helps to reduce the temperatures inside the greenhouse during the hottest hours of the day. The cooling effect is larger in Biskra, as the climate is drier than in Algiers. The simulations show the effects of a humidification system that can evaporate 600 gr/m^2/h.

4.6 Shading

Shading the greenhouse reduces the amount of solar radiation that enters. As an effect, both the air temperature and the crop temperature decrease. Unfortunately, also the potential plant production decreases because less light is available for photosynthesis.

The table 4.3 lists the results of simulations with varying shading percentages. In these particular simulations, the number of too hot hours quickly decreases if some shading (20%) is used. Also, the crop production will increase (in Algiers) because the plants are healthier. If heavier shading is introduced (30% and more), the crop production decreases, because there is not enough light available.

Therefore, we advise to use shading carefully. Ideally, shading should be done with movable curtains, but of course this is not practically possible in single span tunnels. If sand is used to cover the greenhouse, growers should be cautious not to use too much sand. And should, preferably, measure the shading effect of the sand layer.

Table 4.3. The use of different shading percentages and the effect on temperature inside the greenhouse. The tunnel has a limited ventilation capacity, as is the current practice. Note that the simulation period for Algiers is one month longer than for Biskra.

	Ta>30 [hours]	Tcrop>30 [hours]	Ta>35 [hours]	Tcrop>35 [hours]	RH>95% [hours]	plant prod [kg/m2]	plant prod [%]
Algiers, no screen	402	451	172	281	1051	21	100
20%	215	244	30	97	833	23	109
30%	202	215	27	75	886	20	99
40%	191	189	20	46	942	18	86
Biskra, no screen	545	565	320	350	206	17	100
20%	407	369	195	203	110	16	99
30%	381	343	186	181	102	15	90
40%	362	313	169	162	108	13	79

Note on the simulation: If a screen is used in KASPRO, the ventilation rate goes down (as the screen normally hampers the air exchange). However, in a single tunnel (shielded with sand), the ventilation does not decrease with a screen applied. To mimic this in KASPRO, the *windowfraction* is increased when a screen is applied. To test how much the fraction must be increased, I fitted the temperature of an unshielded tunnel with the temperature output of a tunnel with (transparent) screen and larger windows. This results in window fractions of 0.045, 0.05 and 0.06 for screens with 20, 30 and 40% closed fraction.

4.7 Soil covering plastic film

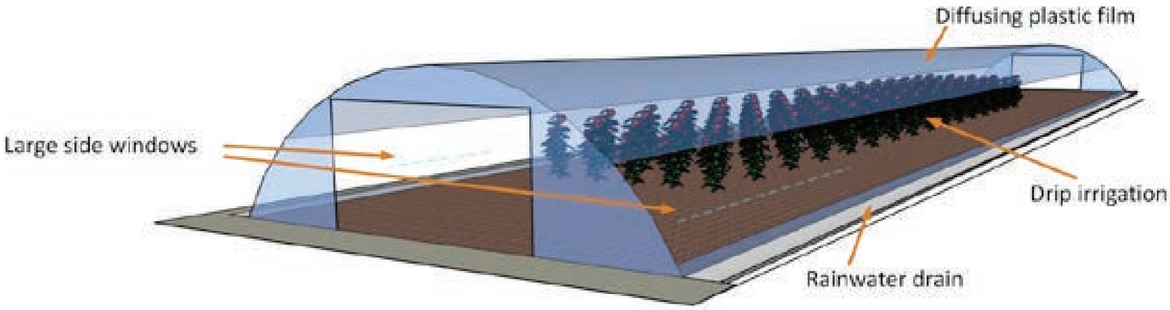
If a greenhouse has no heating system, but does have too low temperatures at night, it is beneficial to use a black plastic foil on the ground (Stanghellini, 2012 personal conversation).
The black foil helps to heat the soil during daytime, and to release the heat into the greenhouse during night time. Of course, the black foil does not reflect the PAR light to the plants, thus the light intensity in the greenhouse is worse than with the use of a white foil. However, in most situations, the benefits of higher night temperatures exceed the drawback of decreased light levels for the plant production.

4.8 Conclusions for single span tunnels

From the calculations above conclusions can be drawn for the regions of Algiers and Biskra:

- Ventilation rate and opening size
  Larger windows do decrease the temperature inside during the hottest hours of the growing season. The opening size should be in the order of 30%. This is very beneficial for the crop, resulting in a potential crop production increase of 50%.
- Cover
  We advise to use a plastic film that is *diffuse* and has a *high transmission of light.* If the film is used on a greenhouse with large windows, it should be thermic (to keep the heat in the greenhouse in winter). If the greenhouse has very limited ventilation, a non-thermic film is probably better as this gives somewhat lower crop temperatures. A diffuse covering material helps to prevent the top of the crop from being overheated by the sun. As the light is distributed over the whole plant, the plant production will increase.
- Evaporative cooling
  Cooling by evaporating water does have a large potential, especially in the warm and very dry climate of Biskra. The temperature inside the greenhouse is substantially lower (about 10 °C) than without cooling and the growing season can be extended. These benefits come at the cost of water use; approximately 20 to 30% of extra water is needed for the production. Moreover, the investment cost for a pad and fan system are high.

- Shading
  The use of screens or coatings (or sand in case of Biskra area) for shading helps to keep the plants alive. However, it also limits the potential plant production because of limited light availability. We advise to use shading to a limited percentage of around 20%. This seems a good compromise between plant health and crop production.



Remark: In the Figure a rainwater drain and drip irrigation is mentioned. Both are applicable in the single tunnel and will be discussed later.

5 Quick scan on PV driven extraction fans

As foreigners it surprised the authors that the use of solar energy was very limited in Algeria, while sunshine was extremely high. It was the reason to check if solar energy could be used to create electricity and to reduce the use of oil or gas.

Mechanical ventilation will improve the climate inside the greenhouse, especially when it is combined with evaporative (pad&fan) cooling systems. Unfortunately, electricity is often not available (or very limited) at the location of low tech, single span tunnels. Therefore, one could consider to use photovoltaic solar panels to supply power to the ventilation system. These systems can be quite simple, as electricity is available at the same time that the power is needed, because during the hottest period of the day the solar radiation is highest.

Let us estimate the energy use of electric ventilators for two cases: (1) A simple ventilation system that helps the natural ventilation. This type of system has mild requirements; a limited capacity and a low pressure drop over the ventilator. The second system is to drive a pad&fan cooling system that can cool the air inside the greenhouse to temperatures lower than ambient. This requires more powerful fans (both flow and pressure difference are higher), resulting in a much higher power input.

Ad. 1. Simple ventilators to help natural ventilation.
The air exchange is set to 50 $m^3/m^2/h$
a pressure difference of 60Pa and a ventilator efficiency of 70%. This results in:
50/3600 * 60 /0.7 = **1.2 W/m^2**

Ad. 2. Pad&fan cooling system
60 air exchanges per hour, greenhouse of 4m high results in an airflow of 240 $m^3/m^2/h$
a pressure difference of 60Pa and a ventilator efficiency of 70%. This results in:
240/3600 * 80 /0.7 = **7.6 W/m^2**

The pump capacity should be in the order of 6 l/m pad/min (Fahmy, 2011). If we assume that the greenhouse is 30m wide, the pump capacity should be around 6*60/30 = 12$l/m^2_{greenhouse}/h$. This results in a power need for the water pump of 12/1000/3600*1e5/0.7 = 0.5 W/m^2

If we assume that the fan and pump should be running for 12hours per day, the daily energy need is (7.6+0.5)*12 = 97Wh/m^2. Part of this energy is needed at times that the solar panels do not deliver their full power (at noon and early morning), so we need a battery system with a limited storage capacity of approximately 40% of the daily energy use (0.4*75 = 39Wh/m^2). Also we should include a safety factor of 70%, to prevent the batteries from discharging completely, resulting in 30/0.7 = 56 Wh/m^2. At 24VDC, this is 2.3 $Ah/m^2_{greenhouse}$.

The investment cost for simple batteries is in the order of 3.5 euro/Ah. (source: autoaccushop.nl). The investment cost for the battery system will be in the order of 8 euro/m^2, which is quite expensive compared to the investment cost for the greenhouse construction.

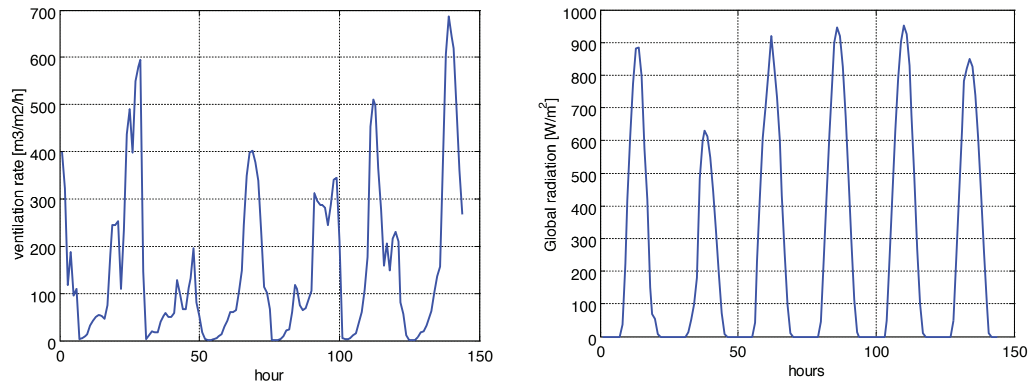


Figure 5.1. Ventilation rate for a greenhouse with evaporative cooling, Biskra climate 10-16 april 2011

The average energy use for the fans is around 100Wh/day to provide the air exchange completely by fans.
Figuur 5.2. shows that the peak in ventilation is not equal to the peak in solar radiation. Therefore, a battery system is needed. At a solar panel size of 1/8 times the greenhouse size, the battery should be approximately 100Wh/m$^2_{greenhouse}$.

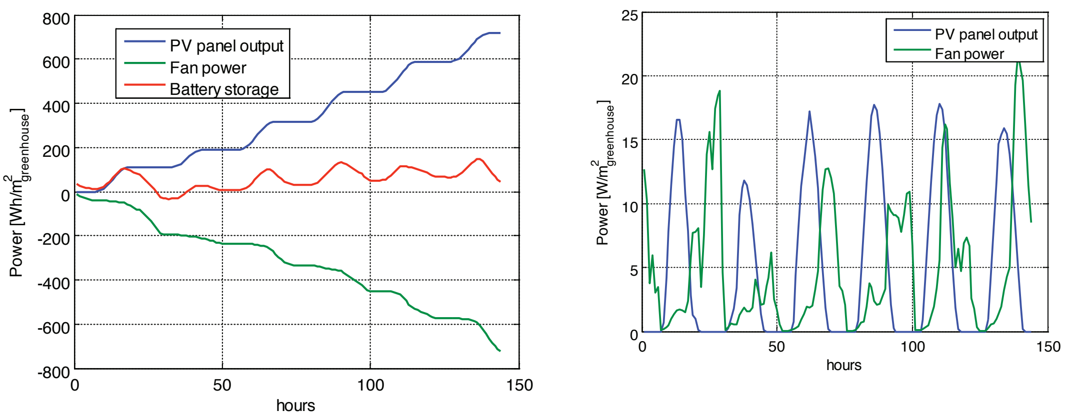


Figure 5.2. Relation ventilation peak and radiation peak.

F. H. Fahmy N. M. Ahmed, H. M. Farghally, and A. A. Nafeh, A Modified Cooling System for Stand Alone PV Greenhouse in Remote Areas; International Conference on Renewable Energies and Power Quality (ICREPQ'11), Las Palmas de Gran Canaria (Spain), 13th to 15th April, 2011.

Conclusions PV driven fans

The use of PV to drive pad&fan systems seems to be a viable idea. Unfortunately, cooling is also needed at times when the solar radiation is less (in the afternoons). A battery would solve this issue, but this requires quite a large investment.

6 Multi span greenhouse

This chapter describes various improvements that can be made to multi span greenhouses. Most improvements to be suggested here will have its price, but can be made economic because of higher yields and better quality.

6.1 Simulation settings

The climate inside the multispan greenhouse is simulated with KASPRO, for which type of greenhouses KASPRO is meant. In the following paragraphs settings for the model are explained. The growing season is similar to that of the single tunnels. Planting date: 15th of September; end of season: 1st of May for Biskra and 1st of June for Algiers. The model assumes that the windows are closed if the temperature inside is too low.

6.2 Ventilation capacity

This section gives an overview of the ventilation capacity that can be reached with natural ventilation with and without insect nets. Also, a cost-benefit of mechanical ventilation is presented.

Natural ventilation is a very efficient mechanism for air exchange in case of wind outside. In warm climates with low wind speeds, mechanical ventilation may be favorable despite the high energy costs for the ventilators. Our greenhouse simulation model (KASPRO) uses advanced algorithms to calculate the ventilation rate of the greenhouse as a function of wind velocity and temperature difference. Therefore, the simulation results are very suitable to determine the best way to ventilate the greenhouse.

6.2.1 Natural ventilation

We have studied the effect of the ventilation capacity in a greenhouse under Algerian climate conditions by installing increasing roof windows in the greenhouse. The number of hours during which the temperature inside the greenhouse exceeds a threshold (30 °C and 35 °C) are given in Table 6.1. This information is used to decide how large the windows in the greenhouse need to be. For example, a window fraction of 0.1 (0.1 m^2 window opening per 1m^2 greenhouse floor surface) results in 175 hours during which the temperature of a crop in Algiers is higher than 30 °C. When the window fraction is increased to 0.4, the number of hours is reduced to 89 and the potential crop production is 9% higher than with a window fraction of 0.1.

Table 6.1. Effect of increasing window fraction on the climate inside the greenhouse and the yearly evapo-transpiration by a tomato crop (2011 climate data).

Window fraction [m^2 window / m^2 greenhouse]	Number of hours warmer than 30 °C [h]		Number of hours warmer than 35 °C [h]		RH [h]		Evapo-transp. [$kg/m^2/yr$]	Crop production [% relative to ref.]
	T air	T crop	T air	T crop	>95%	>90%		
Algiers (1 Sept - 1 Jul)								
0.1	225	175	13	31	2620	4381	544	100
0.2	161	115	3	11	2288	3820	581	105
0.3	128	97	1	6	1985	3498	603	107
0.4	112	89	1	3	1787	3281	617	109
0.5	101	80	0	2	1646	3153	626	109
Ambient	85		0		289	1720		
Biskra (1 Sept - 1 Jun)								
0.1	469	258	174	94	625	1911	627	100
0.2	458	212	156	69	462	1242	662	101
0.3	456	201	144	57	290	919	683	100
0.4	459	197	142	56	206	805	695	99
0.5	469	196	143	52	147	696	706	98
Ambient	517		139		6	86		

Figure 6.1. is a so-called 'duration load curve'. This type of graph is used to study the time during which a certain situation occurs during one year. The Figure is constructed as follows: in simulation we calculate the temperature inside the greenhouse for every hour of the year or growing season. After the simulation, all values are sorted, running from high till low. These values are plotted, so that the Figure gives the amount of hours that a value occurs per year.

To read the graphs, do the following: first, choose a threshold (on the y-axis); for example the number of hours during which the temperature inside the greenhouse is higher than 30 °C. The number of hours during which this occurs can be read from the x-axis; *e.g.* in Biskra, we see that approximately 500 hours are hotter than 30 °C (for all window sizes).

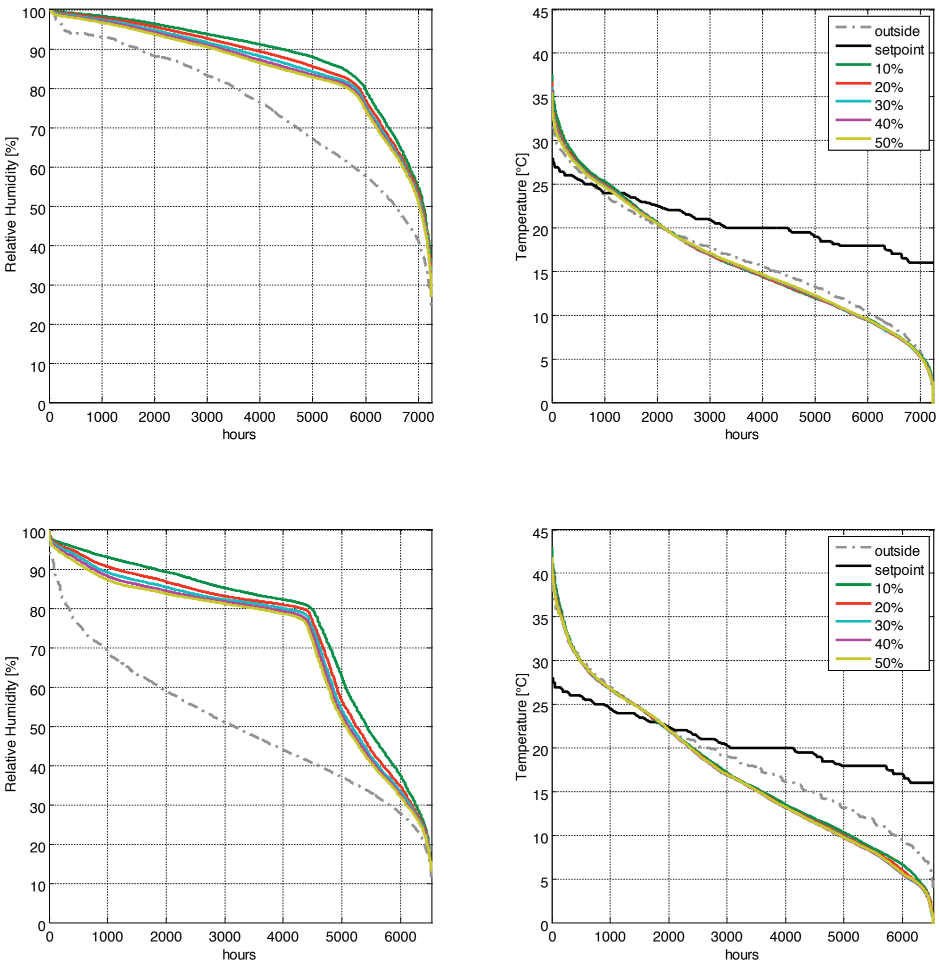


Figure 6.1. Load duration curve for greenhouse air temperature and relative humidity for various window fractions in Algiers (top) and Biskra (bottom) (2011 climate data). Note that in Biskra the growing season is shorter, thus the shorter x-axis.

Conclusion ventilation without insect net

For the temperature inside the greenhouse, the window size is less important than for the humidity. This is mainly caused by the cooling by the plant evaporation; as the plant evaporates water, the air inside the greenhouse is cooled. Also the RH inside the greenhouse increases. Thus, to keep the RH within limits we advise a window percentage of 30% to 40% in Algiers and 30 to 50% in Biskra.

6.2.2 Insect nets

Insects do cause problems and should be rejected from the greenhouse. In Algerian horticulture, most problems are caused by Tuta absoluta (Figure 6.2). This is a small leaf mining moth of 6-8mm that lays eggs on the leaves and stems of plants (especially tomato). The caterpillars live inside the plant tissue; mining damage occurs, which may cause a yield loss up to 100%.

Some biological treatments are possible (Koppert, 2012), but of course it is better to keep the moths out of the greenhouse by insect nets. As the moths are quite large compared to other insects like white fly, the holes in the netting may be relatively large. According to a sales company, the advised hole size to reject Tuta absoluta is around 0,74x1,17 mm and a porosity of 63% (Table 6.2.). The light permeability of the net is around 92% (Howitec Netting 2012).

Figure 6.2. Tuta absoluta the moths (left) and a sample of the netting (right)

Table 6.2. Screen properties depending on the species of insects that must be rejected. (Bailey, 2003).

Insect to be rejected	hole size [mm]	porosity [-]	ventilation reduction factor [-]
Tuta Absoluta	0,74x1,17[2]	0.63[1]	0.14
serpentine leaf miner	0.61	0.64	0.13
sweet potato whitefly	0.46	0.57	0.19
melon aphid	0.34	0.48	0.27
greenhouse whitefly	0.29	0.43	0.32
silverleaf whitefly	0.24	0.38	0.39
western flower thrips	0.19	0.31	0.47

[1] the yarn thickness is 0.26mm for the Tuta absoluta net. All other nets use 0.15mm tick yarn.
[2] source: howitec.nl

The application of insect nets has one disadvantage: the ventilation rate is reduced because the window openings are partly blocked by the nets. Perez Parra (2004) suggest the following equation to calculate the effect of insect net porosity on the ventilation rate:

ventilation = η_{screen} * potential ventilation

and $\eta_{screen} = \zeta_{screen}(2-\zeta_{screen})$

Where η_{screen} is the reduction factor on the ventilation rate and ζ_{screen} is the porosity (m^2 holes/m^2 screen). Table 6.3. shows the required porosity and the ventilation reduction caused by the nets for several insect species.

Table 6.3. Effect of insect nets on indoor greenhouse climate, 2011 climate data. The greenhouse is not equipped with a fogging system in these simulations.

net porosity [%]	Number of hours warmer than 30 °C [h]		Number of hours warmer than 35 °C [h]		RH [h]		Evapo-transp. [kg/m²/yr]
	T air	T crop	T air	T crop	>95%	>90%	
Algiers (1 Sept - 1 Jul)							
No net, 0.4m²/m²	122	164	1	12	1492	3130	653
0.63	129	170	1	13	1549	3201	648
0.63+fog	4	9	0	0	905	1678	367+230(fog)
Ambient	85		0		289	1720	
Biskra (1 Sept - 1 Jun)							
No net 0.4m²/m²	483	265	151	110	166	627	745
0.63	481	271	158	114	199	696	738
0.63+fog	231	226	31	51	201	703	654+514(fog)
Ambient	517		139		6	86	

Conclusions ventilation and insect screens

The main conclusion for the window size is that by increasing the ventilation capacity, the temperature in the greenhouse only very slightly decreases. The RH does decrease however, as the water vapor evaporated by the plant is more easily ventilated away. The effect of increased ventilation on the crop production is positive.

The effect of insect nets with porosity of 63% (against Tuta absoluta) on ventilation is quite limited. If finer nets are used (for example to exclude white fly), the window fraction should be increased by approximately 10%.

In conclusion, we advise to equip the greenhouse with vents of around 0.4 m² ventilation area/m² greenhouse ground floor area in combination with insect nets with a porosity of 63% to reject Tuta absoluta.

Figure 6.3. Insect nets in the window opening of a Venlo-type greenhouse, combined with an external shading screen

6.2.3 Mechanical ventilation

If we would choose to use mechanical ventilation to supply all fresh air to the greenhouse, we would need 1 million m^3 of air per m^2/year (from the KASPRO simulation). The energy need is approximately:
Flow * eff * dP = 1.0e6 * 1/0.8* 100 = 125 MJ m^2/year (= 35 kWh/m^2/year). (where eff = ventilator efficiency [0-1], dP the pressure difference over the ventilator [Pa] and Flow the volumetric airflow [m^3]).
At a cost of 3 DA per kWh, this adds up to 105 DA per m^2 greenhouse per year. Using natural ventilation is for free, therefore it is advised not to use mechanical ventilation, but to use natural ventilation instead.

Conclusion ventilation and insect nets
A greenhouse for the climate in Algeria should be equipped with a well-designed ventilation system. A large ventilation capacity avoids excessive temperatures inside the greenhouse at daytime. The power consumption of mechanical ventilation is high, so we advise to use *natural ventilation*. The vents should be equipped with insect nets to keep Tuta absoluta out.
To provide sufficient ventilation capacity, even with insect nets, the surface of the vents should be at least *0.3 m^2 per m^2 green*house ground surface. In that case, the temperature inside the greenhouse is close the outside temperature. Natural ventilation without additional fogging or cooling is not able to decrease the temperature below the outside temperature level.

6.3 Cover: plastic film or glass

The background on the different cover materials are explained in section 4.4, here only the results for multi span greenhouses are given (Table 6.4).
As in the single span tunnel, a non-thermic diffuse film is the best choice for the climate inside the greenhouse during summer. In winter, a thermic film (or glass) is better to keep the greenhouse warm. However, this effect could also be achieved by installing an automated energy screen (an aluminized screen that insulates the greenhouse at night).

We advise to use a plastic film that is *diffuse* and has a *high transmission of light.* If the film is used on a greenhouse with large windows, it should be thermic (to keep the heat in the greenhouse in winter). If the greenhouse has limited ventilation, a non-thermic film is probably better as this gives somewhat lower crop temperatures. In this case, an energy screen could be used to keep the greenhouse warmer at night.

Practical Algerian aspects
Further practical investigation leaded to the following statements:

- Both types of greenhouses will need:
    - Heating to achieve night temperatures of more than 15 °C via a boiler
    - Boiler on gas or possibly oil is more economic now if there is a connection to the general grid. If no gas grid is available solar heating is a good alternative;
    - Heat buffer storage (200m^3/ha)
    - Use of exhaust gasses to deliver additional CO_2
    - Internal shading/energy screen
    - Insect nets for the windows
    - Sufficient ventilation windows
    - Construction of both types of houses does not differ dramatically in price. Strength is needed against wind, not especially for the difference in weight between glass and plastic.
- *Advantages of Glass*
    - Higher light transmission, thus potentially higher plant yield
    - The higher transmission has 2 main reasons: better properties of glass and better cleaning possibilities (required external glass cleaning)
    - Even better than normal glass is *diffuse* glass; this will increase the yield by more than 10% (shown in

practice) in The Netherlands.
  - More sustainable than plastic film; depreciation in 10 to 15 years.
- *Advantages of plastic film*
  - Cheaper, thus lower investment cost
  - Locally available, more knowledge with cultivation is available in plastic covers than in glass
  - More diffuse light in the greenhouse
  - 3 year lifespan is possible
  - Slightly lower temperatures in greenhouse during the day (if the right plastic is chosen, it will transmit long wave thermal radiation).
- *Skills*
  - To achieve top yields skills of staff have to be improved (for plastic and glass greenhouses)
  - If skills are not yet top, extra yield in glass compared to plastic will not be fully achieved.
  - In first years of cultivation top yields will not be achieved: staff has to learn cropping under different conditions.
- Economics
  - Investments (*approximate*)
    - glass: 6 euro/m^2
    - diffuse glass 6 + 5 = 11 euro/m^2
    - plastic foil 2 euro/m^2

    These are only prices for plastic and glass material, not for construction or other attributes.

Table 6.4. Performance of several cover materials with respect to temperature and potential crop yield in a multispan tunnel (no shading used).

	transm. [%]	Tair>30 [hours]	Tcrop>30 [hours]	T<10 [hours]	yield [%]
Algiers					
glass	67	217	386	1205	100
pt02a	60	177	221	1319	95
pt02c	66	168	169	1391	103
ph03a	65	168	171	1386	102
pk02e	64	140	101	1469	102
local, white	64	155	154	1398	100
local, yellow	59	140	120	1418	95
Biskra					
glass	66	576	518	886	100
pt02a	59	526	341	1109	94
pt02c	64	500	275	1344	103
ph03a	63	503	280	1321	102
pk02e	63	471	199	1562	101
local, white	63	495	257	1346	101
local, yellow	58	481	234	1405	96

[1] Algiers has 85 hours in the growing season with ambient temperatures over 30 °C
[2] Biskra has 517 hours in the growing season with ambient temperatures over 30 °C
[3] Algiers has 1114 hours per year with ambient temperatures under 10 °C
[4] Biskra has 600 hours per year with ambient temperatures under 10 °C

Conclusions

A glass greenhouse has a better *potential* yield but can only be realised by a very experienced grower.

A plastic greenhouse needs more maintenance and replacement of foil every 2-3 years. Investments for a plastic greenhouse are somewhat lower than for a glass greenhouse but maintenance is more expensive.

Production level under a glass cover will, especially the first years, be lower than potential, which means that a glass greenhouse will obtain less returns to compensate the costs. In these first years a glass greenhouse could give worse financial results than a plastic greenhouse; on the midterm the financial results will be better. Locally, more knowledge is available on plastic greenhouses, while labour costs for maintenance are relatively low. For maintenance on a glass greenhouse help from abroad will be needed and will take time (import, delivery). If a close cooperation between foreign glasshouse builders and investors can be made a glass greenhouse can be considered. If such a cooperation is hardly possible a modern plastic greenhouse should be considered, with a thermic foil to keep heat inside in winter.

6.4 Adiabatic cooling

The simplest method of cooling a greenhouse is by means of natural ventilation with large roof ventilation. Additionally cooling by means of fogging may be useful as it has (limited) ability to cool the greenhouse air under outside air temperatures. Application of fogging (also often referred to as misting) is getting more and more attention in horticulture worldwide. Especially in areas with high radiation intensities and low outside humidity, fogging can contribute to more favorable greenhouse climate.

The theoretical explanation of adiabatic cooling is that the enthalpy of the greenhouse air increases (humid air with the same temperature as dry air has a higher enthalpy). The higher the enthalpy, the more energy can be carried off per m^3 air exchange between inner and outer greenhouse air. As the ventilation capacity of a greenhouse is limited, increasing the amount of energy that can be carried off to the outside means that greenhouse air temperatures become lower.

6.4.1 Fogging

Fogging works along the same principle as the well-known pad and fan systems; dry air is cooled by evaporating water. The major difference between pad and fans systems and fogging is the fact that fogging is distributed more evenly through the greenhouse. Also, the electricity consumption of fogging installations is less than the electricity consumption of ventilators that move large quantities of air through the greenhouse. Table 6.5. shows the effect of fogging in terms of the number of hours with unfavorable high temperatures, defined as greenhouse temperatures above 30 °C and hours above 35 °C. In the reference situation, no fogging is applied. The other cases use the fogging installation until the relative humidity of the air is 80%.

The table shows that the effect of fogging is different for the Algiers climate than for the Biskra climate. In Biskra, the fogging capacity can be as high as possible; even at the unrealistically high amount of 2000 g of moisture per hour, the humidity inside the greenhouse seldom exceeds 95%. The temperature of the air and the crop continuously decreases with an increase in the fogging capacity.

In the Algiers climate, fogging has less effect on the indoor conditions, because the outside climate is more humid than in Biskra. If the growth of tomatoes is continued in the summer months (June and July), the effect of fogging is more prominent; the number of hot hours are strongly reduced.

Please note that the stated capacity is the net total fogging capacity. In practice, the nozzles of a fogging installation are never running continuously, but apply the fog by pulses of water. For example when a capacity of 300 $g/m^2/h$ nozzle gives water for 45 seconds per minute, followed by a 15 seconds of rest, the gross fogging capacity is 400 gram per m^2 per hour.

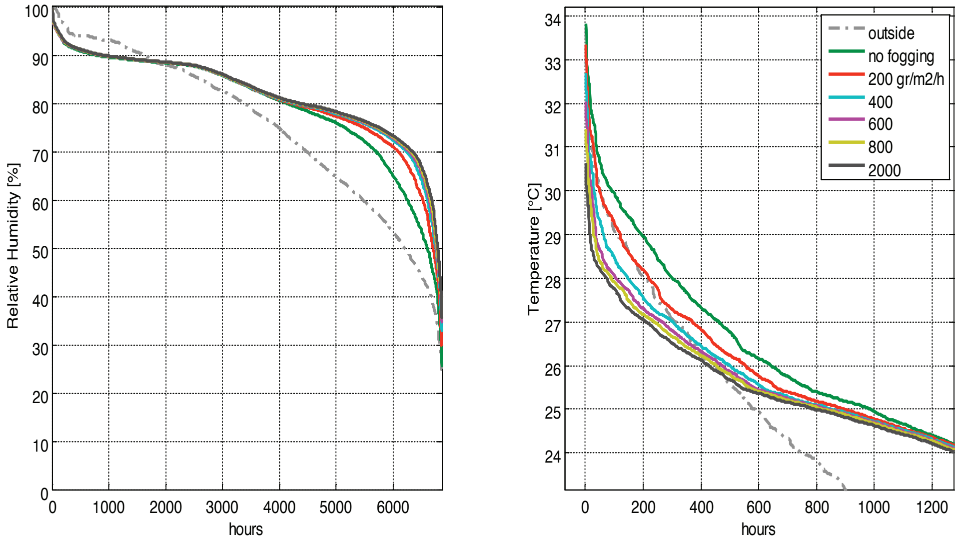
The duration load curves of both air temperature and relative humidity are shown in Figure 6.4.

Table 6.5. Effect of fogging on the amount of hot hours and the yearly amount of water sprayed by the fogging system. (window fraction of 0.5; insect nets; 2011 climate).

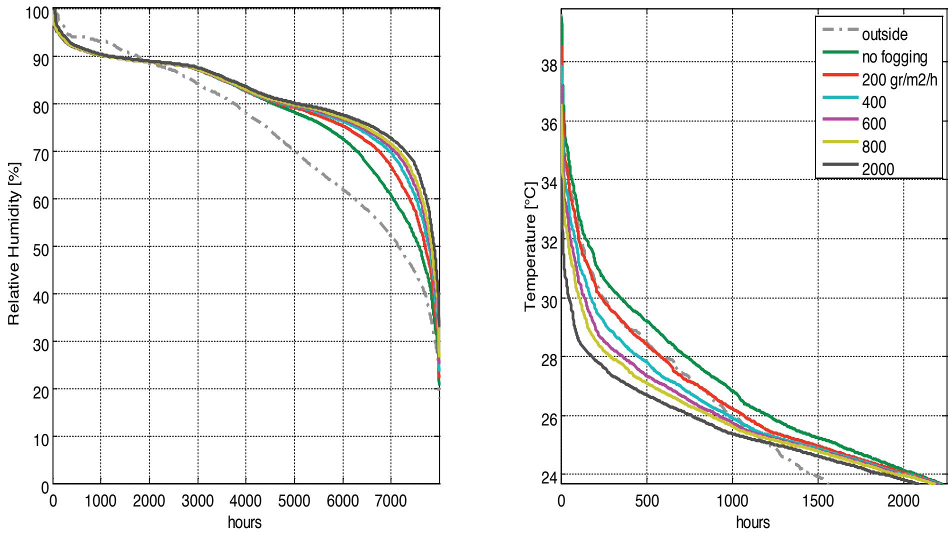
Fogging capacity [g/m²/h]	# hours on	Number of hours warmer than 30 °C [h]		Number of hours warmer than 35 °C [h]		Number of hours with relative humidity higher than 95 or 90%		Evapo-transp [kg/m²/ year]	Yearly fogging [kg/m²/ year]	Biomass increase [%]
		T air	T crop	T air	T crop	95%	90%			
Algiers	(production period 1 Sep - 15 Jun)									
0	0	90	277	0	101	87	769	740	0	100
200	1069	49	298	0	93	90	850	697	138	99
400	1072	30	302	0	88	91	850	685	203	99
600	1072	21	297	0	84	91	851	680	236	100
800	1076	13	296	0	79	98	861	677	253	100
2000	1074	5	289	0	73	108	878	672	266	101
ambient		52		0		279	1637			
Algiers	(production period 1 Sep - 1 Aug)									
0	0	346	577	37	223	111	1038	1015	0	110*
200	1752	233	574	15	184	113	1045	968	257	112*
400	1753	169	560	8	160	115	1047	948	423	118*
600	1754	136	541	5	142	116	1051	937	543	128*
800	1758	102	532	2	127	125	1066	927	626	142*
2000	1760	43	508	0	99	185	1149	892	769	166*
ambient		244		20		289	1749			
Biskra	(production period 1 Sep - 15 Jun)									
0	0	624	529	188	270	0	279	1029	0	100
200	2106	475	526	133	253	1	339	965	323	103
400	2099	381	504	78	231	1	339	932	555	107
600	2103	327	482	47	213	3	345	913	732	110
800	2106	278	468	32	201	11	361	901	869	113
2000	2114	151	410	13	161	86	457	874	1210	120
ambient		591		146		6	86			

* relative to the reference case of no fogging and production period of 1st of September till 15th of June

Algiers



Algiers, 1 aug removal date



Biskra

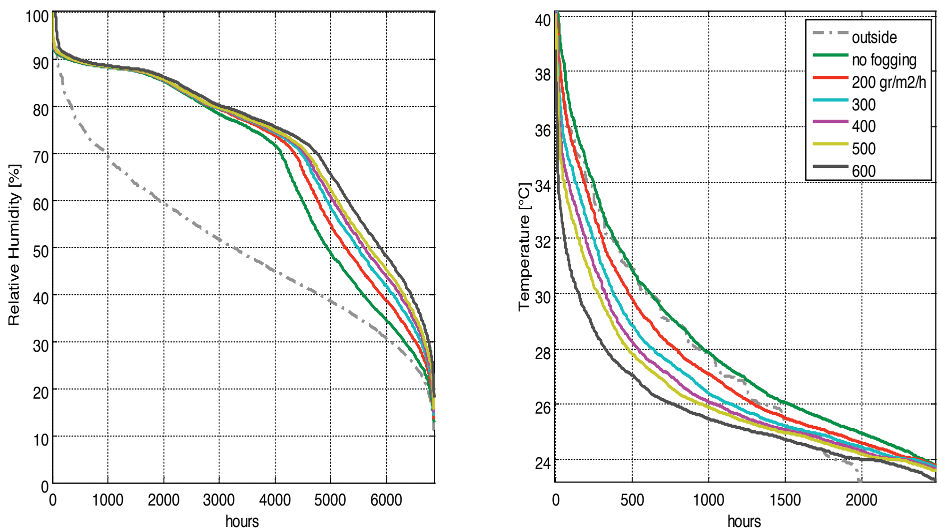


Figure 6.4. Load duration curve for greenhouse air temperature and relative humidity, for a number of fogging capacities in Algiers (top) and Biskra (bottom

6.4.2 Pad and fan

As the operational principle of a pad-and-fan-system is the same as fogging, the operation hours are similar. The main difference is that the required ventilation during these hours is realised by means of fans instead of natural ventilation. This has a higher energy demand than a fogging system in combination with natural ventilation.

The higher energy use is a main drawback of a pad and fan cooling system. Moreover, the climate inside the greenhouse is very inhomogeneous when a pad and fan system is used. To illustrate this, Figure 6.5. is included. At one end of the greenhouse the ambient air enters and is humidified in the pad. Immediately after passing through the pad, the air is cool and humid. As the air travels through the greenhouse, towards the fan, it is heated by the sun. At the fan-side of the greenhouse the air is much warmer, meaning that the local climate is not favorable for the plants. Thus, the average climate may be the same as with the use of a fogging system, the local climate varies a lot for different places inside the greenhouse.

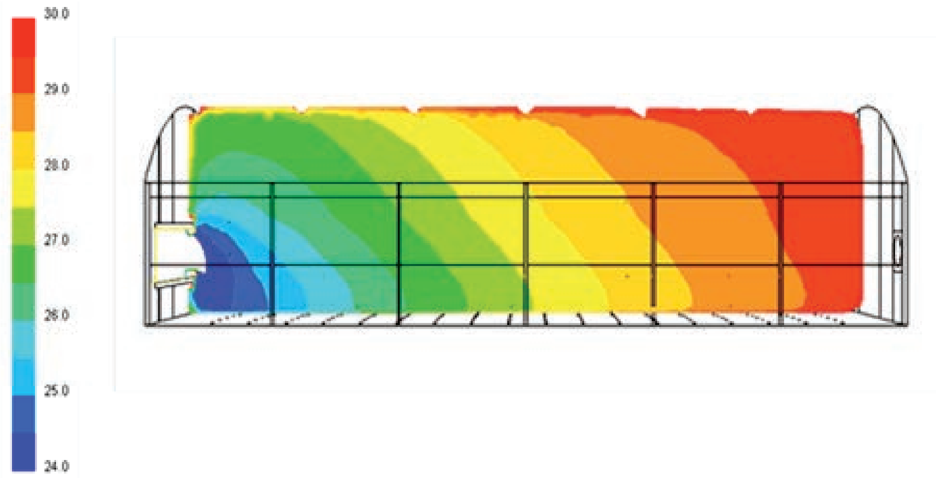


Figure 6.5. Effect of a pad and fan cooling on the temperature profile in a greenhouse. Source: Sapounas, 2010.

6.4.3 Energy use of fogging versus pad and fan

The energy use of a (high pressure) misting system is smaller than that of a pad and fan system. To operate the (high pressure) pump of the misting installation, around 2 W/m^2 is needed. The fans of a pad and fan system will use approximately 7 W/m^2. This means that a pad and fan system uses around 3.4 times more energy than a fogging system. However, in case ground water is used (with bad quality), a reverse osmosis system should be used, which adds another 0.7W/m^2 of energy use to the fogging system.

Estimation of the energy use of fogging and pad-and-fan systems

1. 350 g high pressure fogging/m^2/h	2.1	W/m^2
Power rating of high pressure pump is 50kW/4ha		
Energy consumption of reverse osmosis is 2kWh/m^3 water produced	0.7	W/m^2
2. 80 $m^3/m^2/h$ pad&fan system	7.1	W/m^2
The energy use of the fans is [1]:	6.9	W/m^2
The energy use of the pump is:	0.16	W/m^3

[1] At 50$m^3/m^2/h$, 250Pa pressure difference, fan efficiency of 80%

Conclusion adiabatic cooling

For application in Biskra, it is beneficial for the crop to install a fogging installation with a capacity of 400 to 600 g/m^2/h. The number of hours with high air and crop temperature are strongly reduced, resulting in an increase in potential crop production of 13% (or possibly higher, as fogging will help to stretch the growing season compared to a greenhouse without cooling equipment). The disadvantage of adiabatic cooling is the water use, which is around 800kg/m^2/yr. This water is 'lost' to the outside air.

In Algiers, the effect of a fogging systems is less evident in the normal growing season. If the growing season is extended into the summer (June/July), the fogging system does have a very positive effect on the indoor climate.

Normally, a pad and fan system is not recommended, because of the higher energy cost and inhomogeneous temperature distribution inside the greenhouse. However, there are two prominent advantages of the pad&fan; poor water quality can be used and the investment costs are low. These factors should be considered when making a choice between high-pressure fogging and pad&fan systems.

6.5 CO_2 dosing

Plant photosynthesis is mainly dependent on the amount of light, temperature, humidity, CO_2, water and nutrients available at every moment. During summer time in Algeria temperatures and light levels are high. Assuming water and nutrients can be applied to the extend needed, the amount of naturally available CO_2 limits production.

If CO_2 is added to the greenhouse air, the crop production will increase. However, because a greenhouse in Algerian climate condition needs a lot of ventilation to avoid excessive temperatures, most of the added CO_2 disappears quickly to the outside. Figure 6.6. below shows the *relative* increase in crop production with increasing CO_2 dosing, in modern greenhouses (large windows, heating systems, evaporative cooling systems). The increase in production in Biskra is higher than in Algiers because of the higher solar radiation levels.

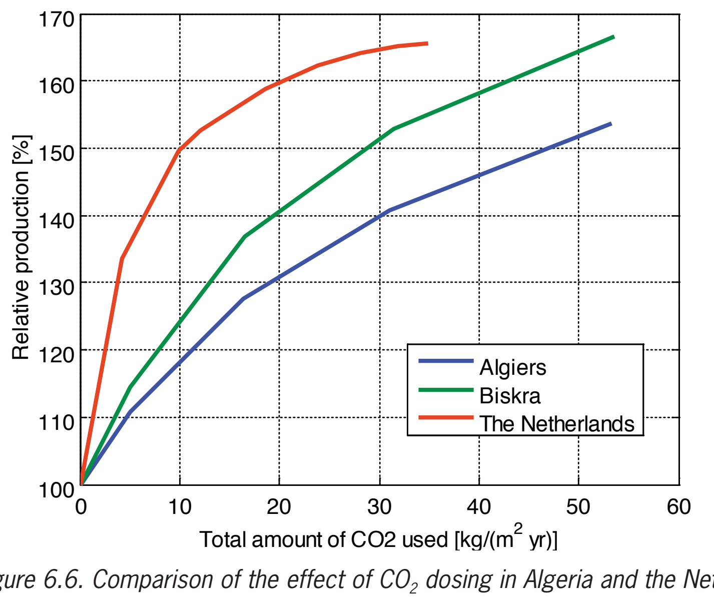


Figure 6.6. Comparison of the effect of CO_2 dosing in Algeria and the Netherlands (at a control set point of 1000ppm). The production increase is relative to plant production at the same location without CO_2 enrichment.

Table 6.6. Effect of CO_2 dosing on the crop yield. The bold line gives the situation in which the CO_2 concentration is increased to 400ppm during daytime. All other lines try to keep the indoor concentration at 1000ppm during daytime.

Algiers		Biskra	
CO_2 dosing [kg/m2/yr]	Yield [%]	CO_2 dosing [kg/m2/yr]	Yield [%]
0	100	0	100
16	123	18	130
31	141	31	153
53	154	54	167
69	160	71	173

When looking at Figure 6.6, we see that the production in a Algerian greenhouse raises with an increased CO_2 dosing. Compared to the reference situation, without CO_2 dosing, 20% production increase can be realized with a dosing capacity of 10kg CO_2 per m^2 per year). Larger dosing systems do increase the production further, however also the costs increase. Compared to colder climates, the benefits of CO_2 are smaller in warm circumstances due to the fact that the windows are opened more often. By opening the windows, CO_2 is lost to the ambient air, which diminishes the effect of CO_2 dosing. To illustrate this, Figure 6.7. shows the window opening in the greenhouse over a whole year, for the situation in Biskra and The Netherlands.

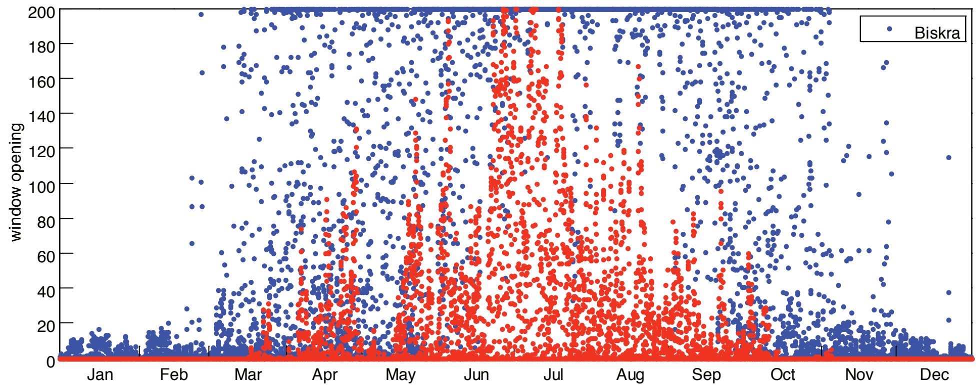


Figure 6.7. Window opening during one year in Biskra (blue) and The Netherlands (red). The value on the y-axis is the sum of the window opening at the windward and leeward site of the greenhouse (both 0-100%).

Figure 6.8. shows the effect of a limited CO_2 dosing system. This system supplies CO_2 into the greenhouse to levels that match the outdoor concentration (400ppm). This results in a production increase of 20-30%, for which 16-18 kg of CO_2 is needed per year.

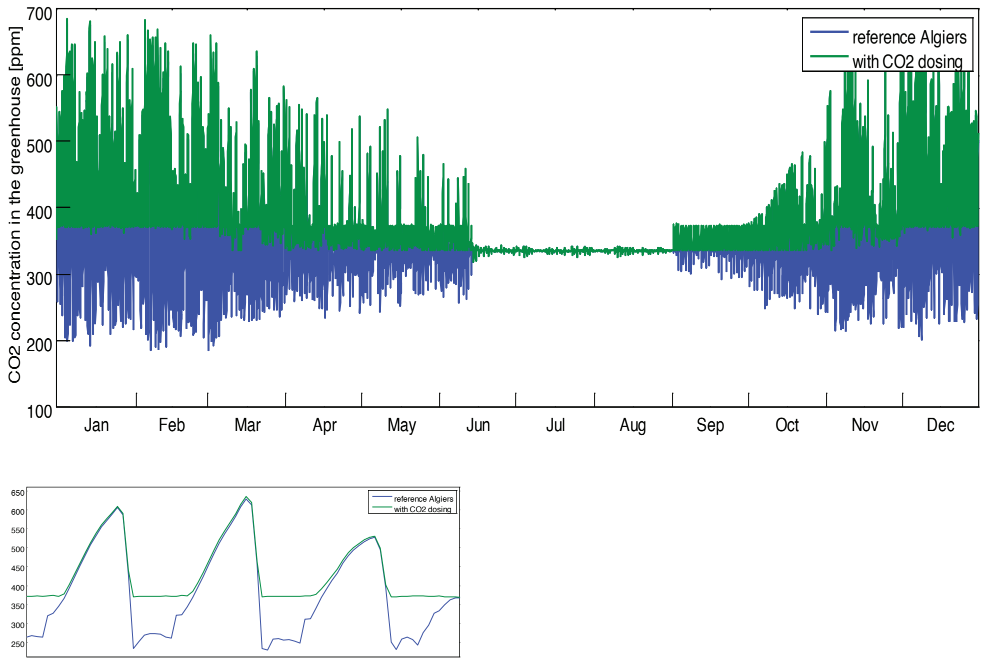


Figure 6.8. The effect of CO_2 dosing in an open greenhouse under Algerian climate conditions. The CO_2 concentration during the day is controlled at 400 ppm (green line), whereas the reference case shows a sharp decrease in daytime CO_2 concentration. At night, the concentrations are similar.

Conclusion CO_2

CO_2 is an essential growth factor for crop production. Although CO_2 is available is the outside air, the dosing of additional CO_2 should be considered during times that the windows are (almost) closed. Especially in the winter months, the CO_2 concentration inside the greenhouse drops sharply, resulting in production losses. In late spring and summer, CO_2 dosing should only be used to replenish the uptake of the plants (thus control the indoor CO_2 concentration to levels equal to outside). The economic cost/benefit analysis of CO_2 dosing determines to what extend CO_2 must be used. This analysis is made in chapter 9.2.3.

6.6 Screens for light control and energy saving

Screens are applied in greenhouses for various reasons: shading and reduction of sun radiation energy input during summer, energy saving by reduction of heat energy losses during winter or both in combination. This section describes considerations that should be taken into account when choosing a screen.

Shading screen

As radiation intensities in Algeria, and especially in Biskra, are quite high, some shading could be beneficial for the crop. Of course, limiting light levels will decrease the potential production, however shading does increase crop quality and decrease risks for crop damage. Two types of screens are commonly used in greenhouse horticulture; internal screens and external screens. Internal screens are cheaper and can be used both for shading as well as for insulation at night. Their main disadvantage is the limiting effect on ventilation, as they block the air exchange between the greenhouse and the windows in the roof. External screens also limit ventilation, however to a lower extend.

Table 6.7. shows the effect of different types of shading screens on the greenhouse and crop temperature, the energy use and the crop production. The screens are closed when the outside global radiation exceeds the given threshold of 500 / 600 / 700 W/m^2. The screen consists for 30% of aluminum foil, thus reducing the indoor radiation by 30%.

From Table 6.7, we conclude that the use of a shading screen does reduce the time at which the temperature in the greenhouse is very warm (>30 °C).

Table 6.7. Effect of different types of shading screens, 2011 climate (incl. fogging (800 g/m²/h) and 0.5 window fraction).

Screen type	# hours closed	Number of hours warmer than 30 °C [h]		Number of hours warmer than 35 °C [h]		Number of hours RH above [h]		Biomass [%]
		T air	T crop	T air	T crop	95%	90%	
Algiers								
reference	0	13	296	0	79	98	861	100
700W, 30% screen	771	0	253	0	15	92	823	95
600W, 30% screen	1137	0	238	0	10	89	826	93
500W, 30% screen	1539	0	211	0	11	91	828	90
permanent screen	always	0	184	0	9	117	1009	68
Biskra								
reference	0	278	468	32	201	11	361	100
700W, 30% screen	1024	230	383	27	147	12	327	95
600W, 30% screen	1407	224	348	24	133	11	323	92
500W, 30% screen	1837	208	331	23	119	13	329	89
permanent screen	always	135	287	16	87	24	515	71

Energy screen
Energy screens are used at night to increase the insulation of the greenhouse roof. This prevents heat loss, resulting in a smaller energy demand of the greenhouse. Although the nights in Algeria are not very cold, installing an energy screen does reduce the heating demand by approximately 20%.
A screen that is primarily used for shading (like the 30% screen from the previous section) gives less reduction in energy use; approximately 5% (Table 6.8).

Table 6.8. Effect of different types of energy screens, 2011 climate.

	Energy use [MJ]	Energy savings [%]
Algiers, no screen	784	0
Algiers, 30% alu screen	760	3
Algiers, 15% open plastic film screen	717	9
Algiers, xls16 screen	638	19
Biskra, no screen	644	0
Algiers, 30% alu screen	602	7
Biskra, 15% open plastic film screen	568	12
Biskra, xls16 screen	502	22

Conclusion screen
Screens are useful to decrease crop temperature during periods with high irradiation. However, due to the lower light transmission the potential crop production is lower when a screen is used often. Moreover, screens limit the air exchange such that the greenhouse temperature will not be substantially lower than without screens in the case of fogging.

We advise to install a screen with 30% shading. This type of screen does not limit the ventilation too much and decreases the risk of crop damage. Also it can be closed at night to limit the heat losses from the greenhouse somewhat.

6.7 Heating demand

The heating demand of a greenhouse in Algeria is fairly limited. However, without any heating system, the temperature inside a greenhouse with a (non thermic) plastic film cover will be lower than 12 °C for 1800 (Algiers) and 1400 (Biskra) hours per year (Table 6.9; green lines in Figure 6.9.). This has a negative effect on the crop growth. Moreover, during the coldest hours, the relative humidity is the highest. A high relative humidity increases the chance for diseases and other crop health problems.

A heating system can keep the greenhouse warm at all times, which helps to keep the crop healthy and increases crop production. A typical greenhouse heating system consists of a boiler and a heat buffer. Most often, the fuel used for the boiler is natural gas. The advantage of using natural gas is that the exhaust gasses can directly be used in the greenhouse to increase the CO_2 concentration. A heat buffer is used for peak shaving purposes; by pre-heating a large tank of water during the day, the peak capacity of the boiler can be reduced. Moreover, if the gas is burned during the day, the CO_2 is available at times when it is most needed for the plants.

A heating system with a capacity of 80 W/m^2 (light-blue lines in Figure 6.9.) is able to keep the greenhouse warmer than 12 °C at all times (both in Algiers as well as Biskra). An even larger boiler capacity of 120 to 150W/m^2 will keep the greenhouse warmer than 15 °C.

Table 6.9. Capacity of the heating system for greenhouses with increasing heating capacity in Algiers and Biskra (2011 climate).

Heating power [W/m^2]	# hours heating system is on	Yearly energy consumption [MJ/m^2]	Number of hours colder than [h]		
			10 °C	12 °C	15 °C
Algiers					
reference	0	0	1182	1811	2876
40	4106	532	69	299	1640
80	3670	756	0	0	398
120	3659	766	0	0	349
ambient			1114	1749	2949
Biskra					
reference	0	0	868	1408	2219
40	3367	428.6	9	205	1140
80	2999	610.7	0	0	172
120	2986	619	0	0	127
ambient			600	1108	2073

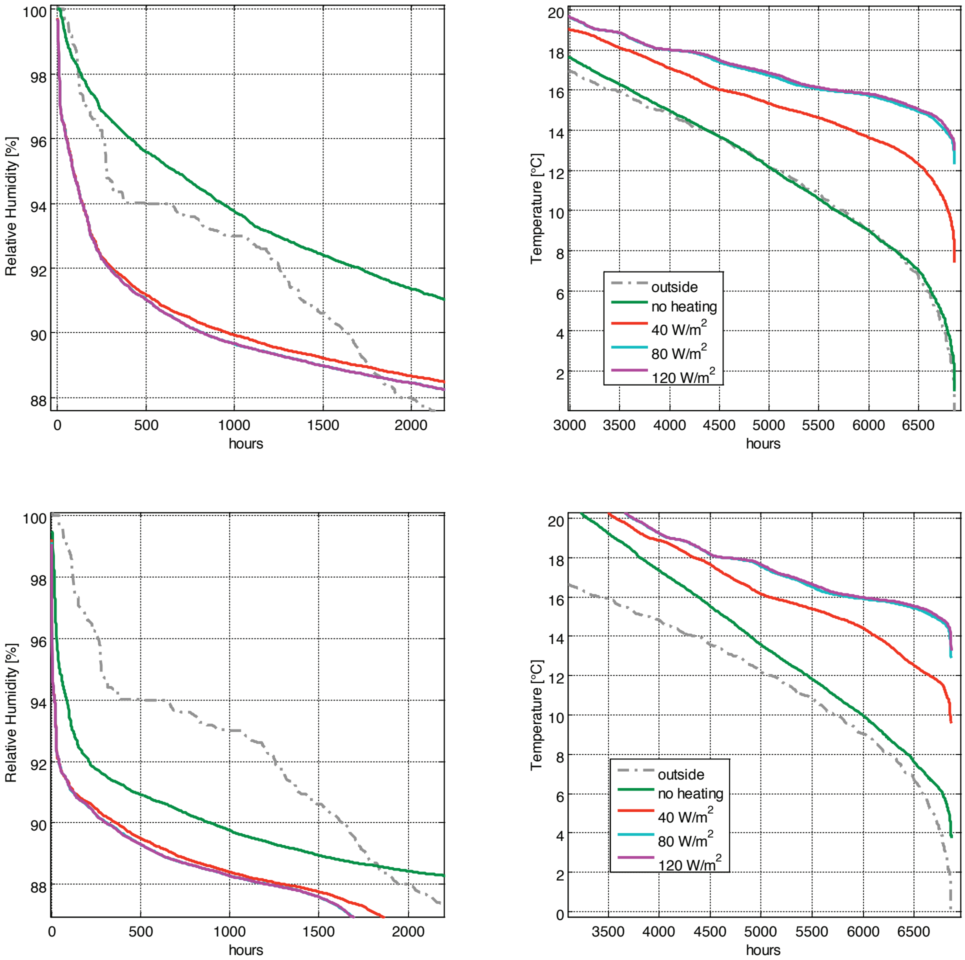


Figure 6.9. Effect of increasing the capacity of the heating system on the indoor temperature (right) and humidity (left) for Algiers (top) and Biskra (lower).

6.7.1 Effect of CO_2 dosing and a heat buffer

If the CO_2 from the boiler is used for CO_2 dosing, a heat buffer is needed to store the heat. This is needed, since the CO_2 from the boiler is directly injected into the greenhouse and cannot be stored. In this way, heat is produced during the day and stored in a large water tank (150 m^3/ha). The hot water is used at night and early morning to heat the greenhouse. The total energy use of the boiler is equal to the situation without using CO_2. Because of the control strategy, the boiler runs for more hours during the year, at a lower capacity (Table 6.10 and Figure 6.10).

Conclusion heating

A heating system in a multispan greenhouse is recommended to avoid cold hours that have negative impact on the crop growth. The capacity of the heating system depends on the type of system that is chosen and the required safety margin on the capacity. Without a heat buffer, a boiler with a capacity of 120W/m^2 is needed to keep the greenhouse warmer than 15 °C during most of the time.

With a buffer of 200m^3/ha, and the application of the exhaust gasses as CO_2 fertilization, the potential crop production goes up with approximately 45% compared to an unheated greenhouse. In this case, a boiler of 40 to 80W/m^2 is applied. An alternative for using natural gas is the application of solar thermal collectors to supply heat to the greenhouse. This option is studied in chapter 6.8.

Table 6.10. Capacity of the heating system for greenhouses with increasing heating capacity in Algiers and Biskra (2011 climate).

Heating power	without CO_2 dosing		with CO_2 dosing	
[W/m²]	Yearly energy consumption [MJ/m²]	Plant production [%]	Yearly energy consumption [MJ/m²]	Plant production [%]
Algiers				
reference	0	100	0	100
40	532	120	570	145
80	756	125	775	153
120	766	125	785	154
Biskra				
reference	0	100	0	100
40	429	116	470	145
80	611	120	643	152
120	619	120	650	152

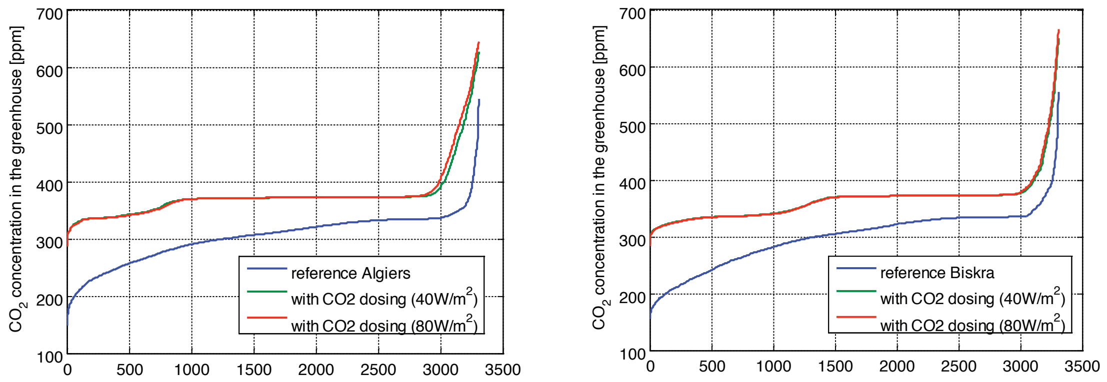


Figure 6.10. Duration load curves for the CO_2 concentration inside the greenhouse during the day in Algiers (left) and Biskra (right)

6.8 Solar energy

An alternative way to provide energy to the greenhouse is to use solar energy. The most simple system that is capable of collecting and utilizing solar energy consists of a solar collector, a buffer tank and a heating system inside the greenhouse (*Figure 6.12 and 6.13*).

Obviously, in a Mediterranean climate the yearly available solar radiation is much higher than the heating demand of the greenhouse. So, if we can (economically) install a buffer to store captured solar heat the greenhouse can easily be heated. In this study we focus on relatively cheap collection and storage systems that use short term (maximum 2 days) storage of solar heat and a simple solar collector. *Figure 6.11*. shows the energy demand of a greenhouse with a boiler of 40W/m² heating capacity in one graph with the direct solar radiation. From this graph we learn that at almost every day the solar radiation is enough to cover the heating demand. At some points in time, the total direct solar radiation is lower than the total heating demand (the green line is lower than the blue line). Increasing the storage capacity, to 2 days, eliminates these days (lower part of *Figure 6.11*.).

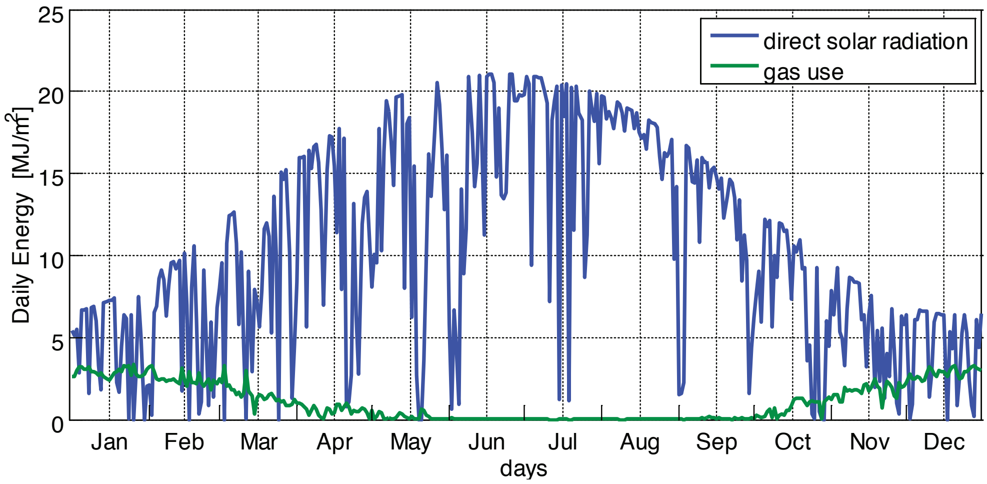


Figure 6.11. Sum of the heating demand of the greenhouse (blue line) and incoming direct solar radiation, for one day (top) and two days (bottom) (Biskra 2011 climate data).

Figure 6.12. a solar collector for greenhouse heating (left; www.certhon.com) and a heat storage tank (right).

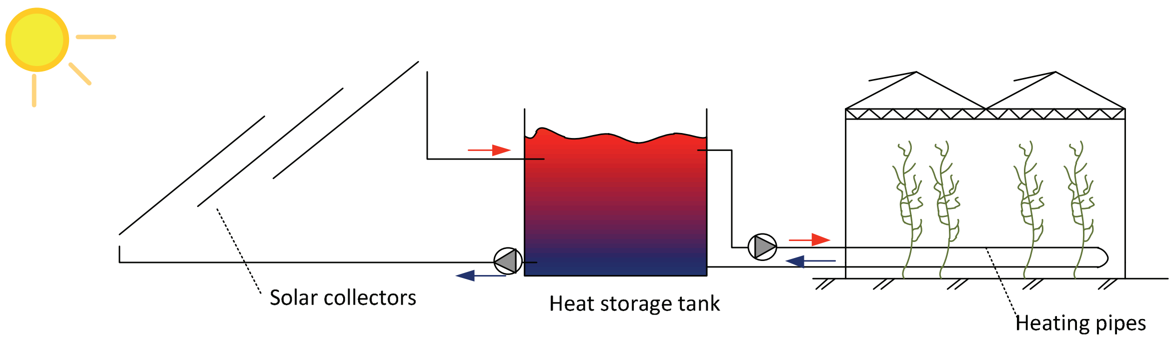


Figure 6.13. Layout of a solar thermal energy collection system

The solar collector is connected to a buffer tank in which hot water (produced with solar heat during daytime) is stored and used at nighttime. The size of the buffer must be chosen such that it fits the solar collector and the heating demand. Varying the size of the solar collector changes the amount of solar heat that can be captured and used to heat the greenhouse, this effect in shown in Table 6.11.

Table 6.11. Influence of the size of the buffer and the solar collector on the temperatures inside a greenhouse in Biskra. The table is sorted on the number of hours during which the greenhouse temperature is lower than 10 °C.

Buffer size [m^3/ha]	Collector size [m^2/m^2 greenhouse]	Hours with T<10 °C	Hours with T<12 °C	Hours with T<15 °C	Approx. investment [euro/m^2][1]
reference	no heating	899	1439	2241	0
100	0.7	204	437	839	37
	0.8	235	482	898	42
	0.9	272	534	955	47
	1.0	314	596	1043	52
200	1.0	186	370	707	54

[1] approximate investment cost (€/m^2) for the boiler or the solar collector for a 2ha size greenhouse, based on: large, low tech solar collector 50 euro/ m^2, storage tank: 200 euro/m^3 (for a large tank, source: Kwin 2010). The installation cost and equipment inside the greenhouse is not included in these numbers.

A heating system in Biskra uses approximately 13 m^3 of natural gas per year (given the quite high calorific value of 42 MJ/ m^3). If we use an optimistic price estimate of 20 eurocent per m^3, a solar heating system can save €2.60 yearly. So, with a 5 year payback time, the maximum investment cost for a solar thermal system is 5*2.6 = €13,- per m^2 greenhouse. This is probably not enough to build a solar collector of 70% of the greenhouse size.

Conclusions solar collector

The greenhouse may be heated either with fossil fuels or by solar energy (or a combination of both). Heating the greenhouse by means of solar energy is sustainable and has low running cost and is applicable in both regions but preferably in Biskra (more radiation, less connections to the electricity grid.

Solar thermal heating does not seem to be economic viable in areas where natural gas is available. In more desolate areas, solar thermal energy is a good opportunity to run the greenhouse independently from external resources.

6.9 Conclusions for adaptations to the multispan tunnel

Ventilation: A large ventilation capacity avoids excessive temperatures inside the greenhouse at daytime. To keep the Relative Humidity within limits we advise a window percentage of 30% to 40% in Algiers and 30 to 50% in Biskra which is more than the usual 10-15%. Insect nets against Tuta absoluta are demanded, with a porosity of 63% decrease in ventilation capacity is quite limited. If finer nets are used (for example to exclude white fly), the window fraction should be increased by approximately 10%.

Glass or plastic: a glass greenhouse has a better *potential* yield which can only be realised by a very experienced grower. A plastic greenhouse needs more maintenance and replacement of foil every 2-3 years. Investments for a plastic greenhouse are somewhat lower than for a glass greenhouse but maintenance is more expensive.

Adiabatic cooling: For application in Biskra, it is beneficial for the crop to install a fogging installation with a capacity of 400 to 600 g/m^2/h. The number of hours with high air and crop temperature are strongly reduced, resulting in an increase in potential crop production of 13% (or possibly higher, as fogging will help to stretch the growing season compared to a greenhouse without cooling equipment). The disadvantage of adiabatic cooling is the water use, which is around 800 L/m^2/yr. This water is 'lost' to the outside air. In Algiers, the effect of a fogging systems is less. Normally, a pad and fan system is not recommended, because of the higher energy cost and inhomogeneous temperature distribution inside the greenhouse. However, pad&fan may work with poor water quality and the investment is low.

CO_2: the dosing of additional CO_2 should be considered during times that the windows are (almost) closed.

Screens: useful to decrease crop temperature during periods with high irradiation. However, screens limit the air exchange. A screen with 30% shading is recommended. This type of screen does not limit the ventilation too much and decreases the risk of crop damage. Also it can be closed at night to limit the heat losses from the greenhouse somewhat.

Heating: for a multispan greenhouse heating is recommended to avoid cold hours that have negative impact on the crop growth. With a buffer of 200m^3/ha, and the application of the exhaust gasses as CO_2 fertilization, the potential crop production goes up with approximately 45% compared to an unheated greenhouse.

Solar collector: Heating the greenhouse by means of solar energy is sustainable and has low running costs and is applicable in both regions but preferably in Biskra (more radiation, less connections to the electricity grid.

7 Use of (rain) water

7.1 Model estimations

The potential use of water can be estimated by use of the model Waterstreams (Voogt *et al.* 2012). Based on three years (2006 - 2009; growing season from Sept. 1st - June 1st) with weather data (temperature, RH, radiation and precipitation) of Algiers the transpiration and water use can be estimated. The estimation was set-up to investigate if it might be useful to build greenhouses in such a way that rainwater might be collected which falls on the cover. For soilless cultivation the supply water needs to be of an excellent quality ([Na] < 0.5 mmol/l). Mostly only rainwater fulfills ([Na] = 0.3 mmol/l) and if there is not enough rainwater an additional source has to be used. In Algiers that may be groundwater ([Na] = 4.0 mmol/l). Recirculation of the nutrient solution takes place, no disinfection and discharge takes place for tomato at a level of [Na] = 8.0 mmol/l and for sweet pepper at [Na] = 6 mmol/l. In the figures below an overview is given for different amounts of precipitation, basin size and crops.

In Table 7.1 rainwater and additional water use are calculated for Algiers in the year 2007 - 2008 with different sizes of the rainwater collection tank for tomato and sweet pepper. It appears that tomato uses more water than precipitated (601 to 510 mm), always an additional source is needed. For sweet pepper transpiration is lower than precipitation. However the utilization of rainwater does not differ very much between the two crops, from 62% for a 250 m^3 basin to 85% for a 1000 m^3 basin. The reason for this is the high precipitation at certain moments (heavy rain showers) which cause the basins to overflow. It also appears that for tomato there is hardly no discharge, while for sweet pepper there is a substantial quantity of nutrient solution which has to be discharged from the system. If you have to use more additional water from a bad quality there is more discharge, especially when the rainwater basin is smaller.

Table 7.1. Model calculation rainwater use for Algiers, season 2006/2007

Algiers			basin size (m^3/ha)		
2006-2007	description		250 m^3/ha	500 m^3/ha	1000 m^3/ha
tomato	precipitation (mm)	510			
	transpiration (mm)	601			
	rainwater (m^3/ha)		3150	3700	4350
	additional water (m^3/ha)		2900	2350	1700
	utilisation (%)		61	72	85
	discharge (m^3/ha)		50	50	50
sweet pepper	precipitation (mm)	510			
	transpiration (mm)	493			
	rainwater (m^3/ha)		3150	3675	4200
	additional water (m^3/ha)		2975	2250	1500
	utilisation (%)		62	72	82
	discharge (m^3/ha)		1175	950	750

In Figuur 7.1. the rainwater collection is presented for a 1000 m^3/ha basin for tomato (left) and sweet pepper (right). In September the basin is empty at the start, consequently one has to start with additional water which rises the [Na] in the lower two graphs. At the moment rain falls you see the filling of the basin and a decrease in the [Na] in the recirculating system. In the lower left graph it can be seen that the [Na] stays below 8 mmol/l for tomato while for sweet pepper (lower right) there is mostly more than 6 mmol/l and consequently discharge (green line) is needed.

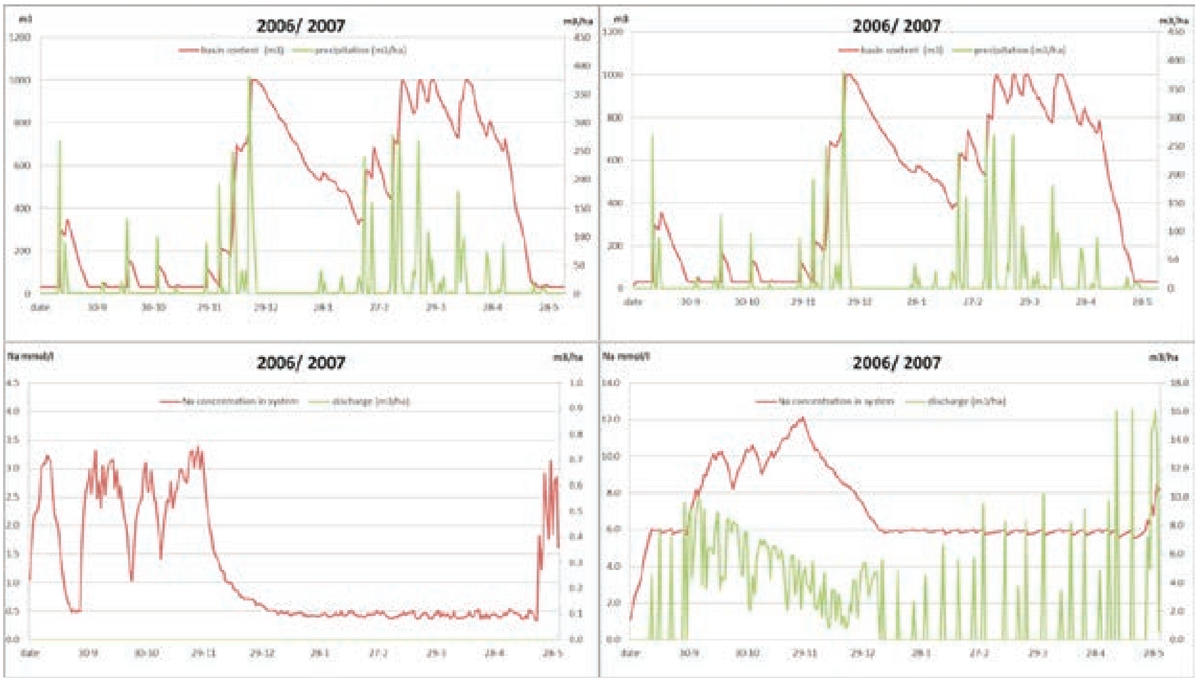


Figure 7.1. Precipitation and filling of rainwater basin (in upper graphs); [Na] in the system and discharge (lower graphs) for tomato (left) and sweet pepper (right) in Algiers, season 2006 - 2007.

The season 2006/2007 was a relative dry year (511mm rain), while 2008/2009 was much wetter (629 mm). In Figuur 7.2. an overview of rainwater utilization in a 500 m^3/ha reservoir is given for tomato in both years. Additional rain falls especially in autumn, reason why after initial water shortage the quality of water is very good. There is little [Na] in the solution (Figuur 7.2. right below). It appears also that rainwater utilization decreases from 72% in 2006/2007 to 69% in 2008/2009 season. This can be explained by overflow of the rainwater collection reservoir, in Figuur 7.2. (upper right) it can be seen that during winter (Nov - Feb) the maximum level of 500 m^3 was often reached, realizing an overflow .

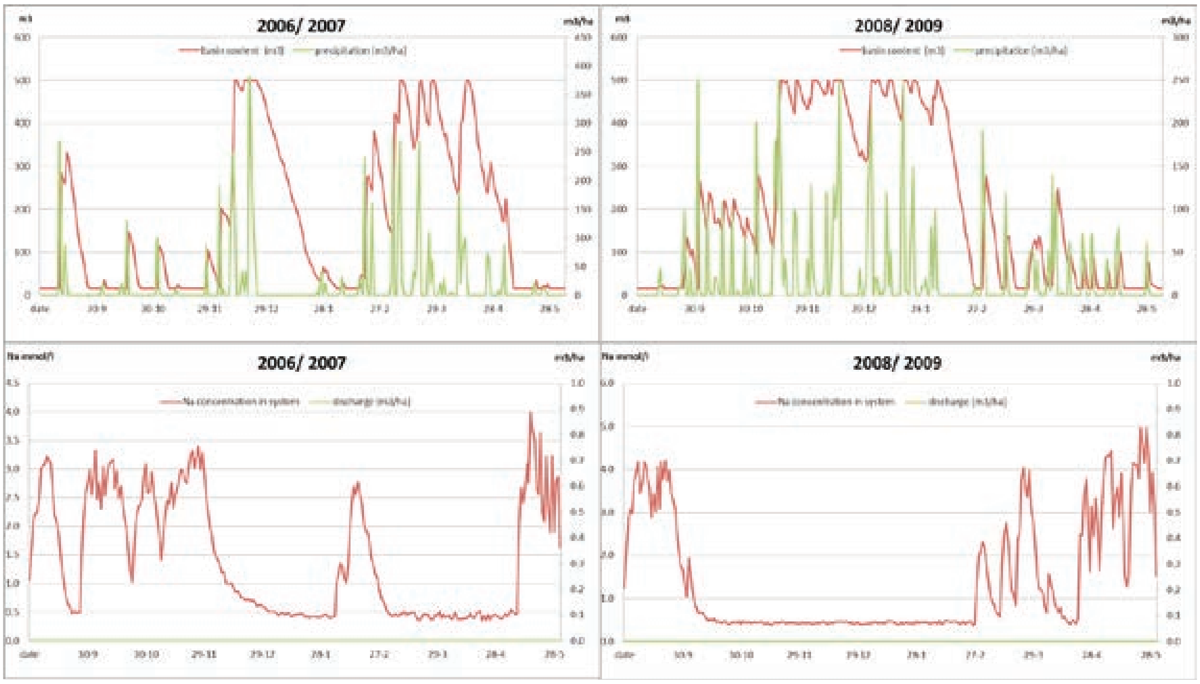


Figure 7.2. Precipitation and filling of rainwater basin (in upper graphs); [Na] in the system and discharge (lower graphs) for tomato in Algiers in the season 2006/2007 (left) and 2008/2009 (right).

In Figuur 7.3. an estimation of the utilization of rainwater is made for a small reservoir of 500 m^3/ha and a larger one of

1000 m^3/ha for the season 2006/2007. Now utilization increases from 72% for a 500m^3 tank to 85% for a 1000 m^3/ha tank. Illustrative is that in Jan/Feb the 500m^3 tank is emptied, while the 1000 m^3 tank has still sufficient water to supply the plants. In the lower graphs a peak in [Na] appears in the 500 m^3 tank which is absent in the 1000 m^3 reservoir.

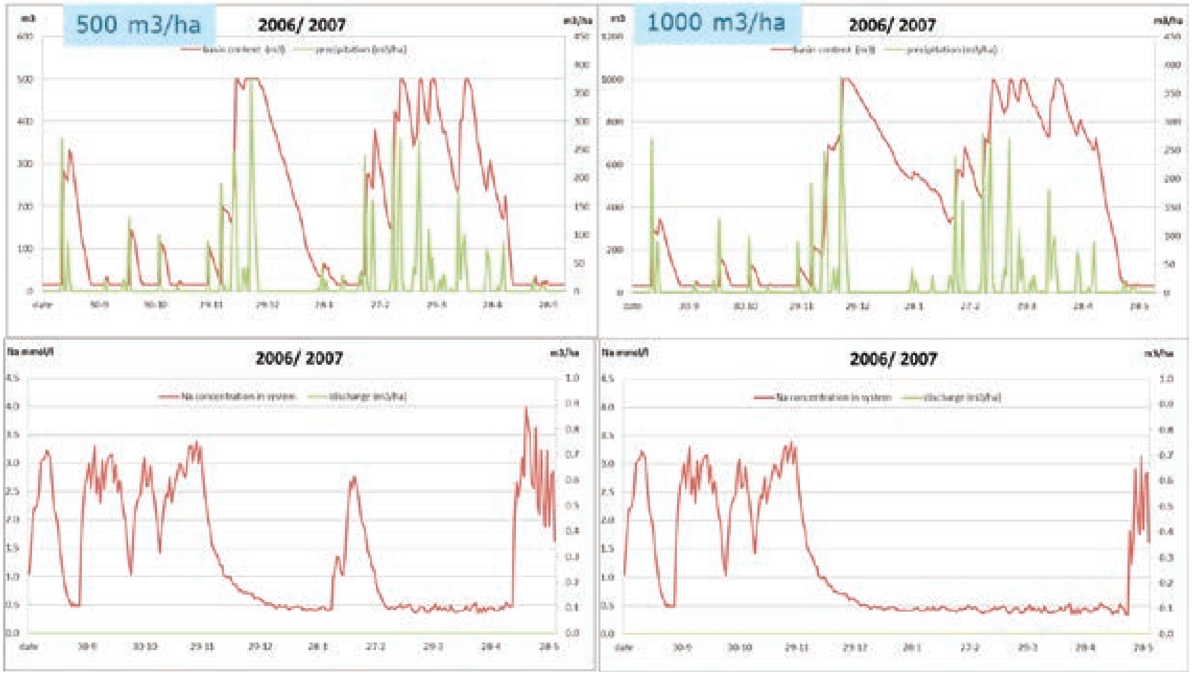


Figure 7.3. Precipitation and filling of rainwater basin (in upper graphs); [Na] in the system and discharge (lower graphs) for tomato in Algiers in the season 2006/2007 for a tank of 500 m^3/ha (left) and 1000 m^3/ha (right).

The question can be raised if heating of the greenhouse influences the water consumption and the utilization of rainwater. In Figuur 7.4. it can be seen that in the 2006/2007 season there are only minor differences between a greenhouse without heating (cold) or with limited heating (light) when using a 1000 m^3/ha reservoir. The utilization of rainwater increases up to 90% because there is less overflow of the reservoir.

If there is no recirculation of the nutrient solution and there is a soilless cultivation all the surplus of nutrients will be discharged. This will be between 20 and 40% of the transpiration and it mainly depends on the quality of water and the system design (uniformity of growth, uniformity of drippers, slope). For tomato, in an open system, about 150 mm (1500 m^3/ha) will be discharged per year which represents about €2250.- which is thrown away, but could be used useful. For sweet pepper, with a lower transpiration, about half will be annually discharged.

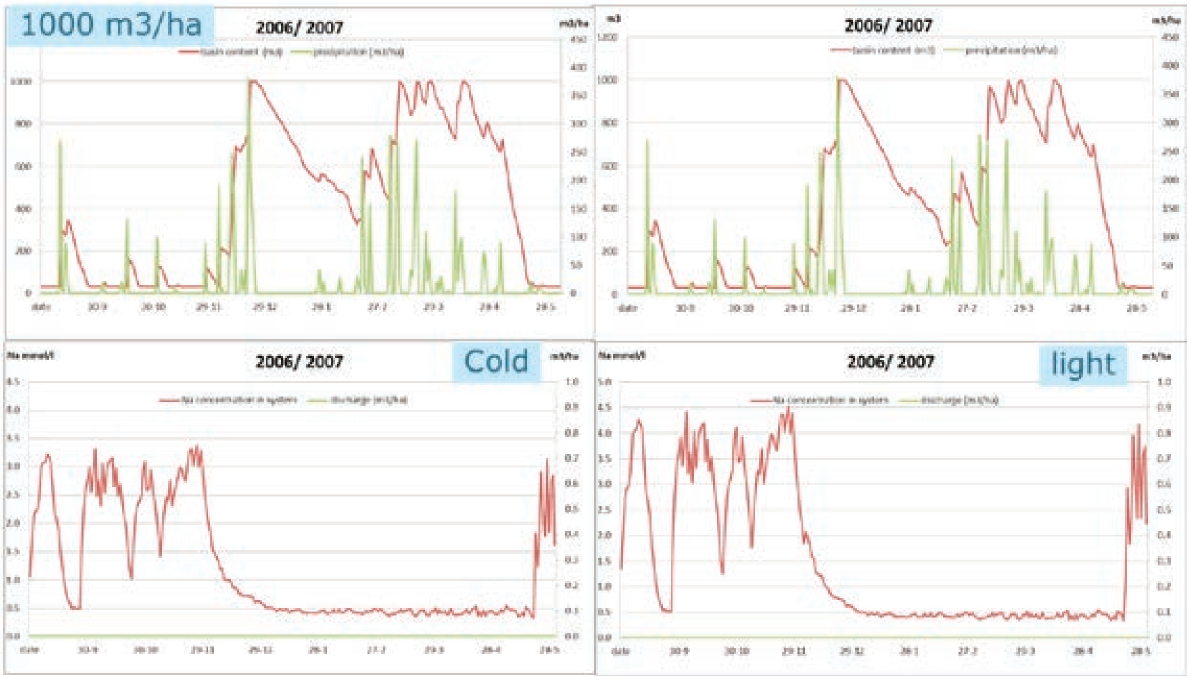


Figure 7.4. Precipitation and filling of rainwater basin (in upper graphs); [Na] in the system and discharge (lower graphs) for tomato in Algiers in the season 2006/2007 for a tank of 1000 m^3/ha without heating of the greenhouse (left; cold)) and with heating (right; light).

7.2 Conclusions rainwater collection

The amount of rainwater which can be collected from the cover of the greenhouses is substantial (75 - 90%) in the Algerian climate with a rainfall of 500-600 mm per year (Algiers). For the region Biskra the need for rainwater collection is much less because of the little rainfall (< 250 mm; no details available) This type of water is of excellent quality and is a major demand for soilless growing methods. A reservoir of 1000 m^3/ha is recommended.

8 Cultivation methods

8.1 Crop production

KASPRO uses a photosynthesis model to estimate the growth and evapotranspiration of the crop. This approach works well to simulate the greenhouse climate and the *potential* crop production. The potential crop production is the production level that can be reached under the given climate (temperatures and solar radiation), if all other factors are optimal. This includes the absence of diseases, optimal plant management and highly skilled workers. In reality, the calculated potential production levels are only reached if the people involved (workers, growers, etc) have deep knowledge and extensive experience with all available technology.
The section below describes the influence of the most important growth factors on the plants and how managing these factors contributes to reach a high crop production level.

8.1.1 How to reach the high potential crop production

The predicted potential production levels are quite high, comparable to the current levels in The Netherlands (55kg/m^2/yr), and very much higher compared to those traditionally reached in Algeria (8 and 10 kg m^2). There are a range of factors which are suboptimal in the traditional Algerian greenhouses. Optimizing these conditions will increase the production level. Furthermore the available light level in Algeria is much higher (especially in winter) compared to The Netherlands, giving a higher production potential.

1. Light
The yearly global radiation in Algeria is 5.5 to 6.5 GJ compared to 3.6 GJ in The Netherlands. When all parameters in the greenhouse are optimal (temperature, relative humidity, CO_2 level), the amount of light determines the production. So based on this assumption the production in greenhouses in Algeria could be up to 50% higher than for The Netherlands. In Arizona, with light levels are 30% higher than in Algeria, a production level of 100 kg tomato m^2 is reached. As the light level of Algeria is almost in between the level of The Netherlands and Arizona (USA) the potential production will be also in between. This indicates a level of 60-80 kg/m^2 of fresh tomatoes should be possible.

2. Temperature control
Algerian greenhouses usually do not have additional heating or (evaporation) cooling systems. This has several effects: (1) The humidity in the greenhouse cannot be controlled properly, leading to additional outbreaks of fungal diseases which have negative effects on the production level. Furthermore, (2) lower average temperatures (at wintertime) lead to reduced growth of the crop and fruits. And, (3) reducing summer peak temperatures by cooling and/or shading improves crop growth.
The optimal average growth temperature for tomato lays around 18-22 ^oC but also depends on the light level and variety. At higher light levels, higher temperatures are required to convert the dry matter production into harvestable tomatoes. Too high temperatures give raise to problems in fruit setting and also increase the stress on the plants (higher dissimilation compared to assimilation). It is estimated from temperature research that better temperature control will lead to production increases of 30%.

3. Production period
Because of the too high temperatures in the summer, the total growth period for tomato in Algeria in greenhouses is limited to about 9 months in multispan greenhouses, but less months are available in single tunnels (too high temperatures) . The first two months are used for growing the crop until the productive stage is reached. This means that the actual production period (period in which fruits are harvested) is limited to 7 months.
Using modern greenhouses with the required climate control systems and substrate growing and management, enables an almost year round production. In total the period in which the greenhouse is “empty” can be minimised to 4-8 weeks only. Taking into account a two month period for growing the crop from planting until productive stage, this means the

actual production period should be increase from 7 to 10 months, being about 2.5-3.0 times more compared to the traditional Algerian production period.

4. Construction/ light transmission of the greenhouse

The traditional Algerian greenhouses have a low light transmission, due to the construction parts used, the covering material and the cropping system. Modern greenhouses have optimized / minimized construction parts, sometimes white coated to increase the light transmission as high as possible (left). The higher light transmission (30% estimate) increases the production. As a rule of thumb 1% more light means 1% more production, if all other factors are managed optimally.

5. Substrate instead of soil

Traditionally in Algeria the crops are grown in soil. Using substrates has several advantages:
Less soil diseases and a much more efficient irrigation and fertigation. Comparison of these two systems over the last decades has shown at least a 15-20% production increase as a result of substrate growing. At low production levels (*e.g.* around 15 kg/m^2, sometimes even a higher production increase is found; up to 50% increase).
A number of growing factors have to be optimized before the forecasted yield can be reached:

- Design and equipment: a soilless system should have an optimized design for all plants. Irregular placing of substrate slabs, incorrect drainage and water supply will influence the uniformity. Equipment is needed to supply the plants at adequate moments with water and fertilizer with a certain EC and pH;
- Water quality: management of an optimized water quality throughout the growing season is important which can be combined with an optimized fertigation strategy based on frequent analyzing of the drainwater.
- Choosing for an open system has other consequences compared to a closed system: EC level of supply water, disinfection of the nutrient solution, availability of excellent water without sodium ([Na]);

However, an average production increase of 20% might be expected.

6. Combining all the above mentioned factors leads to the following rough calculation:

Growth factor	*Production increase*
Light	1.5
Substrate	1.2
Temperature control	1.3
Production period	2.6
Light transmission construction	1.3
Total:	7.9

If we take the current production of 4 kg of cherry tomato per m^2 as a base level, a modern greenhouse will produce around 7.9 * 4 = approximately 30 kg/m^2. However, it cannot be stressed enough: the technology itself will enable to reach the potential high production levels. The actual levels will be reached by the growing of skills as a key success factor. These growing skills include deep knowledge of for example: pruning and leave picking, finding the balance between vegetative and generative growth, choosing the best variety, etc. Not only one manager but all the workers have to be skilled and have to know what they have to watch when working in the greenhouse. The workers see all the plants they can see if there are plagues or diseases, deficiencies, water shortage or surplus or any other growth irregularities.

8.2 Cultivation measures in single and multispan tunnels

The visits to Algeria, the growing systems seen and the potentials available leaded to a number of cultivation measures which can be taken or at least can be compared with the present way of cultivation. Are the suggested measures really better or are other, perhaps hidden, factors more important to avoid introduction?

- *Elongated plant raising period*: now very young plants of less than 3 weeks are planted in an empty greenhouse without climate control in August/September. What would happen if plant raising was done at the specialized plant raiser who spaced the seedlings, raises the plants up to 5-7 weeks with a visible 1st truss, fertigate and support the plants? The growing season is extended (earlier production), the young plant is of good quality without diseases and starts growing in the tunnel and produces more yield per season (up to 2-3 kg/m^2). The plant is also more expensive (greenhouse use, fertilization, water, larger pots, spacing, labour) and transport has to be adapted.

- *One crop cycles instead of two short cycle:* Two crop cycles mean higher costs of plant material and extra labour for planting and removing. In case the crops are planted after each other the production is discontinuous and will result generally in a lower total yield than one long crop cycle. If interplanting is used the production will continue. It depends on the crop variety and the way of harvesting whether the yield will be influenced. Besides interplanting requires more labour to do it carefully. The main objective is to obtain a better product quality and continuation of production. In some cases the production can be realized in seasons with a better product price. It depends on different factors whether the balance of extra costs and extra benefit will be positive. Main argument for choosing of two crops per season is the disease pressure during winter. A high pressure causes a high elimination of plants and, consequently, a decreased yield. The control of diseases is the best medicine to avoid dying of plants because of Phytophthora, Botrytis or any other. In multispan tunnels the use of heating helps very much. Besides good crop maintenance also helps. One crop is preferred; two crops is only useful if the crop will not survive the humid winter period.
- *Closed cultivation system*: a closed cultivation system reduces the discharge of nutrients to ground or surface water and subsoil. A simple drainage and collector system can be earned back by the lower consumption of water and fertilizers. If the drainwater has to be disinfected before reuse the costs are generally higher than the savings of water and nutrients (Montero *et al.* 2012; Euphoros project), which mainly depends on the price of the fertilizers and the disinfection method. However, environmental regulations, differing per country, may influence the choice of one or the other. Before implementing a closed cultivation system the availability of knowledge and experience about soilless culture is required. The risks of mistakes may have a big economic impact.
- *Training system:* now the plant rows are often 1.5 - 2 m from each other, reason is mostly humidity. A humid microclimate arises when rows are too close to each other. In The Netherlands heating the greenhouses solves that problem. However if more rows are used and the ventilation capacity is raised 2 rows of plants can be trained in a high wire system, especially in the multispan tunnel house, in such a way that space utilization is optimised. One row is trained from the main path to the side wall, while the other row is trained from the side wall to the main path. At both ends plants cross the row and form a cycle. Yield is optimised at a height of about 0.9 - 1.4 m which can easily be reached. The red tomatoes are hanging free and are easily seen by the pickers. For turning the heads into the string additional stilts can be used.
- *Internal transport:* if the soil is leveled in a proper way the aisles are a little higher than the rows with plants. The aisles keep always dry and the soil hardens and is easy for transport with carts on rubber wheels. Drainwater is guided to the space between two rows without an aisle or just close to the row. If the soil is leveled on a slope of about 0.5% the water can be guided to the front or backside of the tunnel, realizing no inconveniences. The use of a good internal transport system makes work easier and faster.
- *Disinfection of the soil:* after frequent cultivation of tomato, sweet pepper and aubergines in the same soil nematodes will grow and damage a next crop. Crop rotation may avoid the problem but often there are no sufficient other crops available which are also economic. Disinfction of the soil may help. In sunny warm countries which have an empty greenhouse in summer soil solarization may be a cheap solution. By covering the soil with black film and closing the tunnel soil temperatures may reach 50-70 °C in 4-8 weeks.
- *Automation and registration:* registration of inside and outside temperatures, relative humidities (min, max and average) and radiation is a first step to know what happened in a greenhouse. A datalogger on a computer is optimal, but making an Excel file with these data also helps. Additionally cultivation aspects as EC, pH, start of yield and quantity/quality can be registered too.

9 Economics of greenhouse production and marketing of vegetables

Algeria has a surface of more than 8000 ha with protected cultivation of horticultural products, mainly vegetables. Protected cultivation is mainly conducted in single plastic tunnels. A minor 100-150 ha has multispan greenhouses (multispan tunnel) and canarian type of greenhouses (flat cover). Plastic is the only covering material, although sometimes synthetic netting is used. The most important products in plastic greenhouses are tomatoes, sweet pepper (poivron) and hot pepper (piment). Other products are aubergine and courgette. The products are delivered to wholesale markets. The most important wholesale markets are located in the North of Algeria and are state organisations. The products are bought by commissioners and being sold to retailers, grocery shops and other wholesale markets. In addition also some import products are being sold on the wholesale market. Most products are transported in plastic boxes of 5-10 kg as bulk. There is hardly no grading, cooling and/or packaging. Packaging and cooling is developing and done by private companies. The destination of the products is the domestic market. There is hardly no export. The price setting on the wholesale market is done by the commissioners together and depends on the supply and the demands for products. The commissioners operate with a fee of maximum 8% of the price. The vegetable products are finally sold to consumers on the local market, retail, etc. The product quality in the shop is not always as it should be. Due to bulk transport and no cooling the product presentation is sometimes rather poor.

In the following part of the economic analysis the focus is on the tomato crop, because tomato is the most important greenhouse crop.

9.1 Economics of current greenhouse production

Cost-benefit analysis

Greenhouse vegetable production appear in different regions of Algeria. In this report we focus on two greenhouse regions: coastal area (Algiers) and mid/south Algeria (Biskra). Both regions differ in climate (radiation, temperature, humidity and rainfall) and have as a consequence different cultivation periods.

The cultivation season in the two regions are:

- Coastal area (Algiers): October - June
- Mid-South area (Biskra): September - April.

In both regions three types of plastic greenhouses occur: the single tunnel, the canarian (or parral) multi-span and the multispan tunnel (see Figure 9.1.).

Figure 9.1. Picture of single tunnel, canarian greenhouse and multispan tunnel (from left to right) (Photo WUR Greenhouse Horticulture)

In Table 9.1. the investments of the three greenhouse types are mentioned. All types of structures are covered with a plastic film.

Table 9.1. Investment in a single tunnel, canarian greenhouse and multispan -tunnel (€/m²)

Investment	Unit	Single tunnel	Canarian multi-span	Multi-tunnel
Structure	€/m²	3.8	15.0	35.0
Irrigation system	€/m²	0.4	0.4	0.4
Other equipment	€/m²	.	5.0	5.0
Total	€/m²	4.2	20.4	40.4

Source: Amrar (ITCMI), 2012. Figure based on a calculation for 1 ha.

Table 9.1. points out that the total investment in greenhouses varies from 4.2 €/m² (single tunnel) to more than 40 €/m² (multispan tunnel) or 415 to 4040 DA/m² (1 euro ~ 100 dinar (DA)). The investment of the single tunnel doesn't include the plastic cover, because it is used for one year and is therefore part of the exploitation costs. The plastic cover is part of the investment for the canarian multi-span and multispan tunnel greenhouse (lifespan 3 years). The investment of a canarian multi-span and a multispan tunnel greenhouse may vary in specific situations depending on the high-tech level of the greenhouse (materials, type of ventilation system, type of plastic cover, etc.).

The cost and benefit structure for a tomato crop is given in Table 9.2. These are rough estimations, because no distinction is made between regions with their specific climatic conditions.

According to Table 9.2 a tomato crop results in a positive net profit of 0.6 (single tunnel) to 1.5 €/m² (multispan tunnel). The yield increases tremendously when instead of a single tunnel (8 kg/m²) a canarian greenhouse-span (18 kg/m²) or a multispan tunnel greenhouse (25 kg/m²) is installed. The yield is higher because the cultivation season is longer and the greenhouse climate can be better controlled.
For the revenue a uniform product price of 0.3 €/kg (or 30 DA/kg) is assumed. During the field trip in October 2012 it is being told that the product prices of vegetables from the Biskra region will be higher than from the coastal area, because Biskra growers start earlier with producing and can profit from early and higher prices. The cost price of the production systems varies between 0.22 and 0.24 €/kg.
The main cost components are equipment (incl. plastic cover) and labour. Especially for the multi-tunnel greenhouse the yearly cost of equipment and labour determine to a large extend the total costs. The above mentioned figures will be used for estimating the costs and benefit of the improved greenhouse designs.

Table 9.2. Benefit and costs of a tomato crop in a single tunnel, canarian greenhouse and a multispan tunnel (€/m² and %).

Cost benefit structure tomato crop	Unit	Single tunnel	Canarian multi-span	Multi-tunnel
Yield	kg/m²	8	18	25
Revenue	€/m²	2.4	5.4	7.5
Total costs	€/m²	1.9	4.0	6.0
Net profit	€/m²	0.6	1.4	1.5
Cost price	€/m²	0.24	0.22	0.24
Cost distribution:				
Seed/plants	%	6.8	3.3	2.2
Water & fertilizers	%	11.8	5.8	3.8
Crop protection	%	6.1	3.0	2.0
Plastic cover	%	25.6	0.0	0.0
Labour	%	17.9	21.2	15.3
Equipment (depreciation, maintenance)	%	21.5	61.6	73.3
Others	%	10.2	5.0	3.3
Total	%	100	100	100

Source: Amrar (ITCMI), 2012. Figure based on a calculation for 1 ha.

Wholesale and producers price

Producer prices of vegetable products like tomato were hard to gather. For that reason wholesale price were gathered to get insight in the development during different seasons and years. Besides, the wholesale price was used to estimate the product price of tomatoes with respect to the cost-benefit analysis of improved greenhouse designs (see 9.2). In

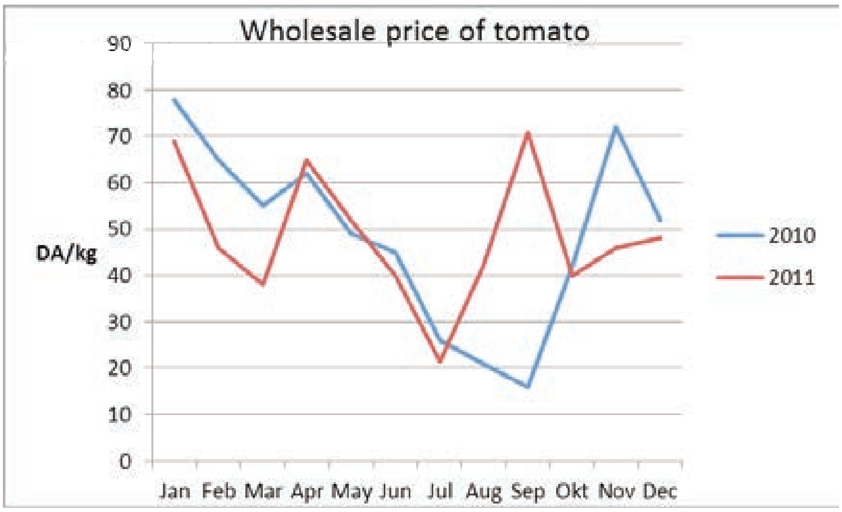


Figure 9.2. the wholesale price of tomato is showed for two years. Source: DSA, 2012

The wholesale price of tomato varies between 80 DA/kg (January) to 15 DA/kg (July-September). The average year-round wholesale price of tomato was 48.5 DA/kg in 2010 and 51 DA/kg in 2011.
If the harvest season of the coastal area (December-June) and Biskra (November-April) is taken into account than the average wholesale price is calculated at ca. 55 respectively ca. 57 DA/kg.
The producers price of tomato is estimated at roughly 70% of the wholesale price. This means that the average producer price of tomato is estimated at 40 DA/kg for the coastal area and 41.5 DA/kg for the Biskra area. These product prices will be used for the economic evaluation of the new greenhouse designs.

9.2 Economics of improved greenhouse production

9.2.1 Introduction

The improved greenhouse production systems contain the following designs depending on the type of greenhouse structure:

Single tunnel:
- Simulated reference (A)
- (A) plus improved ventilation (large windows)
- (A) plus improved ventilation plus pad & fan cooling system.

Multispan tunnel:
- Simulated reference (B)
- (B) plus improved ventilation (large windows)
- (B) plus improved ventilation plus pad & fan cooling system
- (B) plus improved ventilation plus pad & fan plus heating & CO_2 from boiler.

Above mentioned production systems are evaluated for both the coastal region (Algiers) as well as the region around Biskra (Mid/South).

The simulated reference (A and B) concerns a description of the current greenhouse production system with the dynamic simulation model KASPRO (see 2.3). The alternative greenhouse designs differ from each other in the way they can control the greenhouse climate in order to achieve a longer cultivation period and consequently a higher yield level. More detailed information about the designs is described in chapter 4.8 and 6.
The cost-benefit analyses comprises an estimation of the costs and benefits, the payback period and a sensitivity analysis. The cost-benefit calculation covers all costs and benefits:

- Benefit: yield and revenues of product
- Variable costs: plant material, energy, water, growing medium, crop protection, fertilizers, packaging and sales costs, etc.
- Labour costs: cultivation and management
- Fixed costs: equipment (depreciation, maintenance and interest) and general costs.

The balance of total revenues and total costs is the net result.
For the improved greenhouse systems the payback period is calculated (investment/cash flow) and moreover a sensitivity analysis is conducted for the investment and the product price.

In the cost-benefit analysis the following assumptions have been used:

- Good cultivation conditions: sufficient availability and good quality of the needs for the tomato cultivation, such as plant material, water, energy, labour, etc.
- Good cultivation knowledge: required knowledge about climate control, nutrient management, pest control, etc.
- Above assumptions are the basis for the model simulations and the calculated results, like potential yield, use of energy and water and the need of labour
- Pilot crop is tomato with specific product prices for the coastal and Biskra region.

An overview of all assumptions for the cost-benefit analysis is listed in 2.5.

9.2.2 Single tunnel

The cost benefit calculation of the reference production system unfortunately appear not to correspond with the figures in Table 9.2:

- the calculated yield is much higher than according Amrar (2012), but may be caused to a more theoretical approach (calculated) and a more practical approach (Amrar, 2012).
- the calculated yield differs very much between the two regions. The calculated yield in a single tunnel in the coastal region is twice the yield in the Biskra region, which is mainly caused by the better indoor climate and the longer growing season. As a consequence the net result of the reference single tunnel in the coastal region is much higher than that in the Biskra region (see annex 2).

For these reasons the financial results of the improved greenhouse systems are presented in comparison to the simulated reference system (a partial cost-benefit analysis). The thought is that the assumptions (like cultivation period) of the model simulation will have similar effects on the greenhouse designs as on the reference system in a specific region. The basic financial results are listed in annex 2.
The financial results of the improved designs in comparison to the reference system of the single tunnel are shown in Table 9.3.

Table 9.3. Financial overview of improved single tunnel designs in comparison to the simulated reference production system (DA/m2).

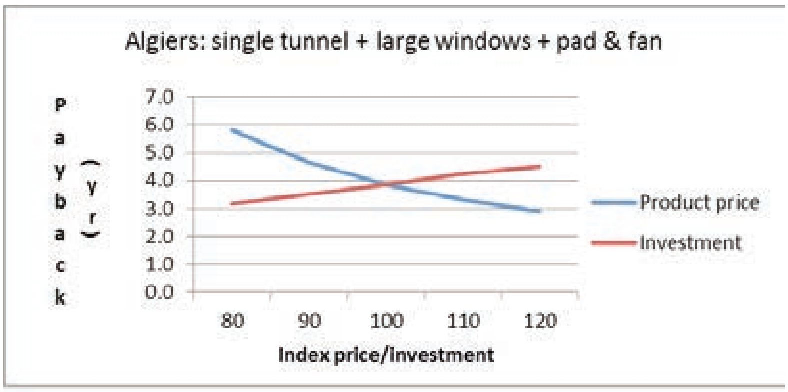
Single tunnel	Algiers		Biskra	
Compared to reference single tunnel	Large windows	Large windows + pad&fan	Large windows	Large windows + pad&fan
Extra investment	105	1383	105	1383
Extra variable costs	43	92	22	81
Extra labour costs	37	56	30	63
Extra equipment costs	11	376	11	376
Extra total costs	92	524	62	521
Extra yield (kg/m2)	10.0	15.0	8.0	17.0
Extra revenues	400	600	332	706
Extra net result	308	76	270	185
Payback period (yr)	< 1	3.9	< 1	3

Table 9.3. points out that an improved ventilation with large windows results in the highest increase of the net result in both regions. An extra investment in larger windows of 105 DA/m^2 realizes a higher net result of almost 310 DA/m^2 in coastal region and 270 DA/m^2 in the Biskra region. The extra costs are relatively low in comparison to the extra yield and revenues. The absolute net result for large windows is positive in both regions (see annex 1).
The single tunnel design with large windows and pad & fan system (cooling) improves the total yield and revenues, but does also require a much higher investment (ca. 1385 DA/m^2) than that of the reference system. The extra annual costs of equipment increases with ca. 375 DA/m^2. As a consequence the extra net result is lower than that of the single tunnel with only large windows. Nevertheless the absolute net result of the single tunnel with large windows and pad & fan is positive (see annex 3).

Payback period
The extra investment in a single tunnel with large windows can be paid back within one year in both regions. The short payback period and the relatively low extra investment of large windows (+7%, see annex 3) can be seen as a low risk for the grower.
For the single tunnel with large windows and pad & fan the payback period of the extra investment is 4 year in Algiers and 3 year in Biskra (see Table 9.3). The risks of this greenhouse design for the growers are higher, especially because of the high extra investment (total investment of this multispan tunnel design is almost twice the reference multispan tunnel system, see annex 4).

Sensitivity analysis
The product price level and investment level has in general a great influence on the financial results. The effect of a fluctuation in product price and investment (80% to 120% of assumed price level) on the payback period have been calculated (see Figure 9.3.). It points out that the payback period of the single tunnel with large windows will maintain within one year when the product price or investment will vary between 80% and 120%. The effect of price volatility of the product or the investment on the payback period is limited. For the single tunnel with large windows and pad & fan the payback period will vary more as is shown in Figure 9.3. The payback period varies between 3 and 6 years as a

consequence of varying product prices in Algiers and between 2 and 4 years in the Biskra region.
The effect of varying investment levels is less than that of varying product prices. In Algiers region the payback period varies between 3.2 and 4.6 years and in Biskra between 2.4 and 3.5 years.



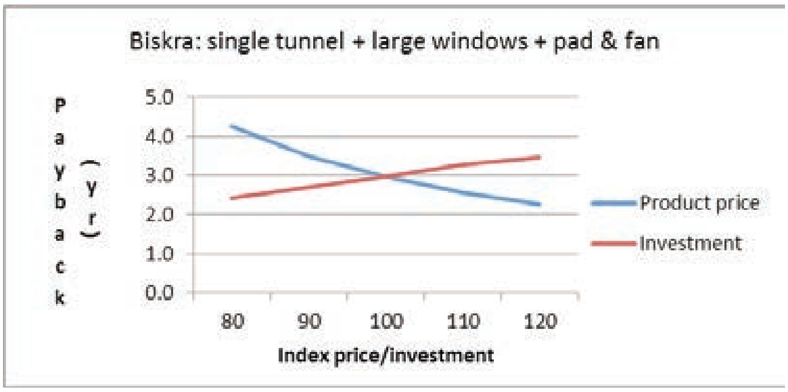


Figure 9.3. Effect of variation in product price and investment (in %) on payback period (in year) for the single tunnel with large windows and pad & fan in two regions (Algiers and Biskra).

9.2.3 Multispan tunnel greenhouse

Also for the multispan tunnel greenhouse the simulated reference system differ considerably from the figures from practice (see Table 9.2). In this case the calculated yield in the Biskra region (17 kg/m^2, see annex 4) is much lower than that obtained in practice (25 kg/m^2, see Table 9.2), although the simulation model assumes good cultivation conditions and the availability of good cultivation knowledge. Moreover the simulated yield in the both regions differ considerably. Therefore again the financial results of the improved multispan tunnel designs will be presented in comparison to the simulated reference system in the specific region. The basic financial results are listed in annex 4.

The financial results of the improved designs in comparison to the reference system of the multispan tunnel greenhouse are shown in Table 9.4. Table 9.4. shows that both the improved multispan tunnel design with large windows as well as the multispan tunnel design with large windows, pad & fan and heating/CO_2 give the best financial results. The design with only large windows hardly require extra investments, so this multispan tunnel design has the best prospects for the Algerian growers (lowest risk). The more 'high-tech' multispan tunnel design (large windows, pad & fan and heating/CO_2) requires a much higher investment (ca. 2400 DA/m^2) than that of the reference multispan tunnel. Although it results in higher revenues it also leads to higher costs for energy, labour and equipment. The multispan tunnel design with large windows and pad & fan improves the net result compared to the reference system (see Table 9.4), but is less favourable than the above mentioned multispan tunnel designs. A pad & fan system seems a less interesting multispan tunnel improvement for the Algiers area, but for the (dry) Biskra region it offers more possibilities. The pad & fan system however does require more and high quality water.

Table 9.4. Financial overview of improved multispan tunnel designs in comparison to the simulated reference production system (DA/m^2).

Multispan tunnel	Algiers			Biskra		
Compared to reference multispan tunnel	Large windows	large windows + pad&fan	large windows + pad&fan + heating + CO_2	Large windows	large windows + pad&fan	large windows + pad&fan + heating + CO_2
Extra investment	0	1200	2395	0	1200	2395
Extra variable costs	24	70	384	19	78	362
Extra labour costs	34	48	119	26	60	119
Extra equipment costs	0	342	482	0	342	482
Extra total costs	58	460	986	45	480	963
Extra yield (kg/m2)	9.0	13.0	32.0	7.0	16.0	32.0
Extra revenues	360	520	1280	291	664	1328
Extra net result	302	60	294	246	184	365
Payback period (year)	.	3.8	3.7	.	2.7	3.3

Payback period

As already mentioned the installation of only larger windows in a multispan tunnel greenhouse doesn't hardly require an extra investment. So the payback period is not calculated. This also means that this multispan tunnel design implies a rather low risk for the growers.

The payback period of the multispan tunnel design with large windows, pad & fan and heating/CO_2 is more than 3 years in the Biskra region and almost 4 years in the Algiers region. The total investment of this multispan tunnel design is 1.5 times the total investment of the reference system (see annex 4). The extra high investment implies a higher risk to the grower. The multispan tunnel design with large windows and pad & fan system realizes a payback period of almost 3 years in the Biskra region and almost 4 years in the Algiers region. The total investment is 25% higher than that of the reference system (see annex 4).

Sensitivity analysis

The effect of a fluctuation in product price and investment (80% to 120% of assumed price level) on the payback period of the different multispan tunnel designs is shown in Figure 9.4. As expected the payback period of the different multi-tunnel designs is more sensitive to changes of product prices than to changes of investment amounts. The payback of the multispan tunnel with large windows and pad & fan varies between 5.7 and 2.9 year in the Algiers region when the product price varies from 80% to 120% (Biskra: 3.9 respectively 2.1 year). The multispan tunnel with large windows, pad & fan and heating/CO_2 show payback periods between 6 and 2.6 year in Algiers (Biskra: 5.2 respectively 2.4 year) when the product price varies from 80% to 120%. For both multispan tunnel designs the range of payback period is smaller when the extra investment varies between 80% and 120%.

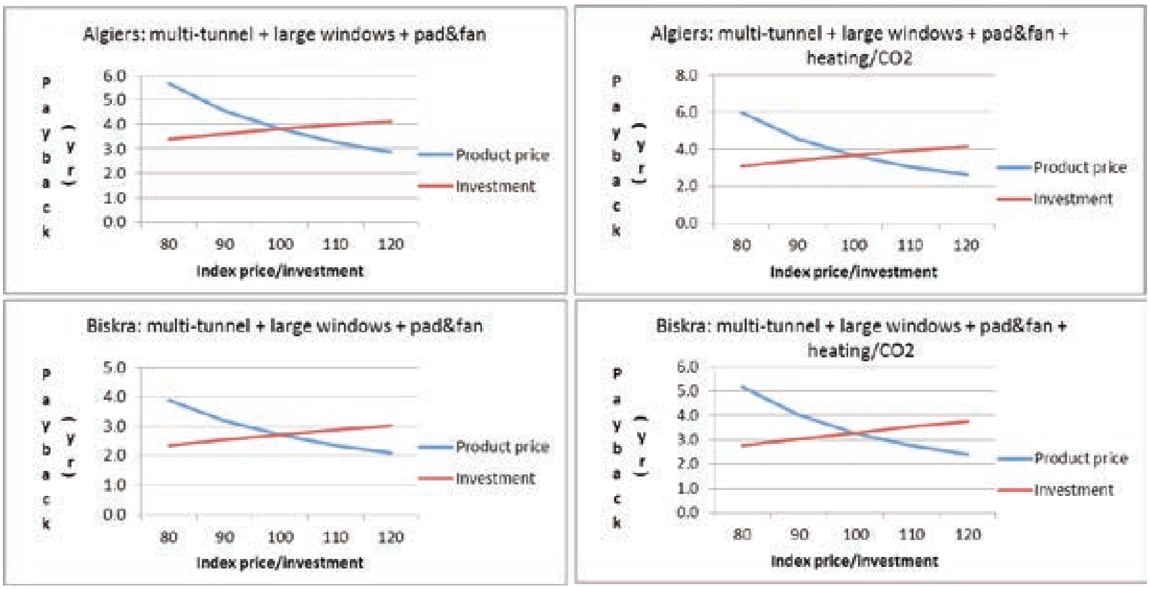


Figure 9.4. Effect of variation in product price and investment (%) on payback period (year) for the multi-span tunnel with large windows and pad & fan and multispan tunnel with large windows, pad & fan and heating/CO_2 in two regions (Algiers and Biskra).

9.2.4 Conclusions

The outcome of the simulated reference system for the single tunnel and the multispan tunnel appear not to correspond completely with the figures of the current single tunnel and multispan tunnel in practice. For that a partial cost-benefit analysis has been conducted in which the improved (single and multispan) tunnel designs have been compared with the simulated reference tunnel system.

The calculations point out that improved ventilation with large windows in both a single tunnel as well as in the multispan tunnel show the best extra net result in both regions. The payback period of the single tunnel with large windows (extra investment: 105 DA/m^2) is one year and the effect of price volatility of product or investment is low. Large windows in a multispan tunnel greenhouse hardly requires an extra investment in case of new establishment.

The multispan tunnel design with large windows, pad & fan system and heating/CO_2 realizes also good financial results and are similar to the multispan tunnel with large windows. In Biskra the extra net result is even higher than the multi-tunnel with large windows. This multispan tunnel design requires a high extra investment (ca. 2400 DA/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 deteriorates the financial results, but show better financial results than the simulated reference tunnel system. Nevertheless the pad & fan system appear to show better financial results in the (dry) Biskra region than in the (humid) Algiers region in both the single tunnel as well as the multispan tunnel greenhouse.

9.3 Market situation of vegetables

In this part general information is showed about the trade (export/import), production and consumption of vegetable products in Algeria. These are vegetables from open field and protected cultivation.

9.3.1 Trade

The export and import of vegetables in Algeria consist of different products. Based on the source Comtrade the following vegetables can be distinguished (vegetables belonging to the HS Code classification chapter 7):

- Potatoes, fresh or chilled
- Tomatoes, fresh or chilled
- Onions, shallots, garlic, leeks and other alliaceous vegetables, fresh or chilled.
- Cabbages, cauliflowers, kohlrata, kala and similar edible brassicas, fresh or chilled
- Lettuce (lactuca sativa) and chicory (cichorium s pp), fresh or chilled
- Carrots, turnips, salad beetroot, salsify, celeriac, radishes and similar edible roots, fresh or chilled
- Cucumbers or gherkins, fresh or chilled
- Leguminous vegetables, shelled or unshelled, fresh or chilled
- Other vegetables, fresh or chilled
- Vegetables (uncooked or cooked by steaming or boiling in water), frozen
- Vegetables provisionally preserved (for example, by sulphur dioxide gas, in brine, in sulphur water
- Dried vegetables, whole, cut, sliced, broken or in powder, but not further prepared
- Dried leguminous vegetables, shelled, whether or not skinned or split
- Manioc, arrowroot, salep, jerusalem artichokes, sweet potatoes and similar roots and tubers.

Export

In Figure 9.5. the export of Algerian vegetable products is mentioned per destination and in Figure 9.6. the most important export vegetable products are showed.

The current vegetable export from Algeria is USD 5.6 million (2011). The most important export products are:

- onions (USD 4.2 million, 2011), mainly to Italy and Tunesia;
- mushrooms and truffles (USD 1.2 million, 2011) to the Middle East.

In 2011 the main export destinations were Italy (USD 2.2 million), Tunesia (USD 2 million) and Quatar (USD 0.8 million). The export increased since 2002, but since 2007 the export of vegetable products (in USD) kept more or less stable. In 2009 an export peak of USD 16.1 million was reported. This was mainly due to an tremendous increase of mushroom and truffle export to Kuwait, Quatar, Syria and the Arab Emirates (see Figure 9.5.). The export of vegetable products like tomatoes and other fruit vegetables (sweet pepper, egg-plant, cucumber) is very small (Figure 9.6).

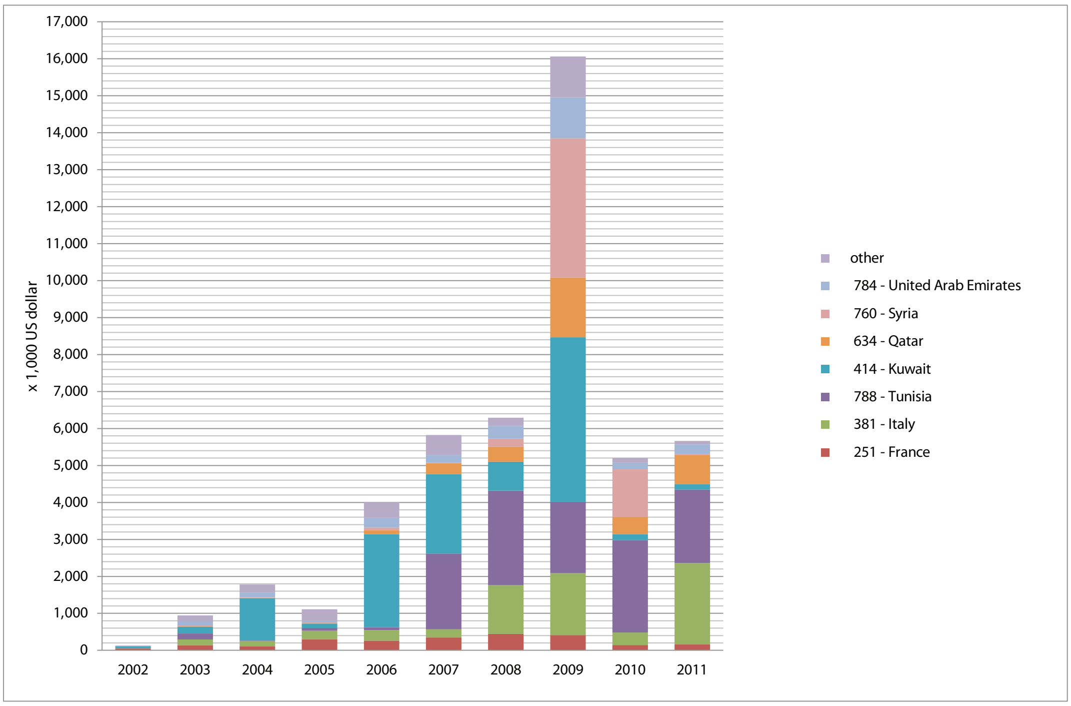


Figure 9.5. Algerian export of vegetables per country (2002-2011) ; Source: Comtrade.

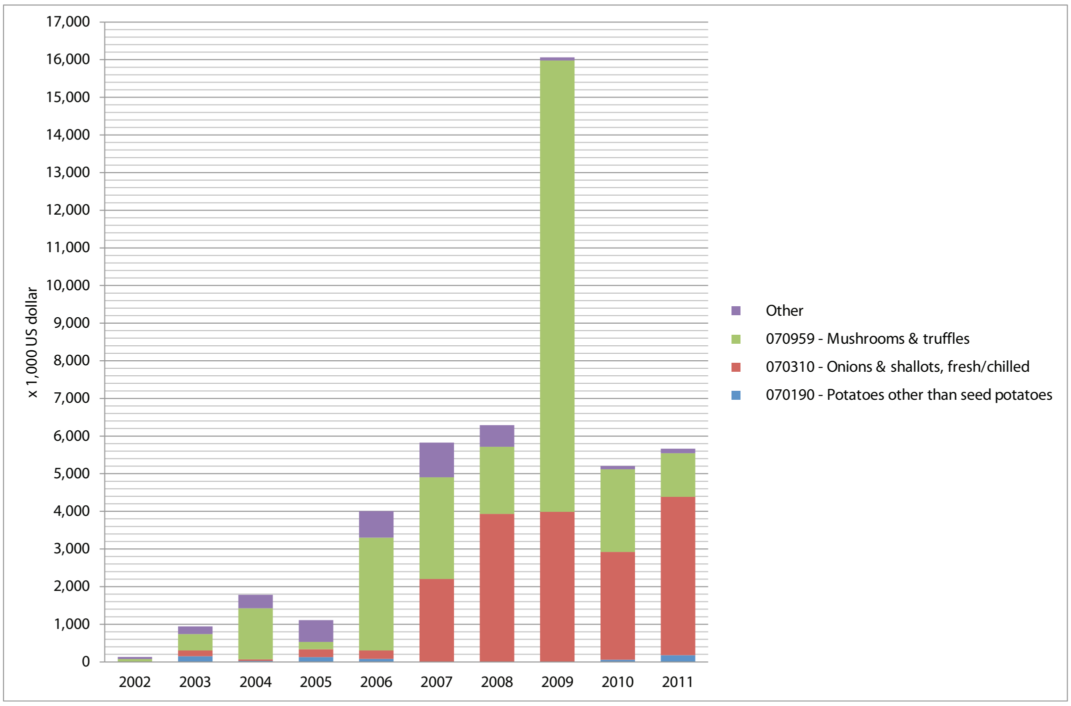


Figure 9.6. Algerian export per vegetable product 2002-2011; Source: Comtrade.

Import.

The current vegetable import exceeds far more the exports (see Figure 9.7.). The import of vegetables was USD 391 million in 2011 (export: 5.1 million USD). In 2011 the main import partners where Canada (USD 86.7 million), India (USD 62.4 million) and The Netherlands (USD 61.7 million). Algerian import from the Netherlands concerns mainly seed potato.

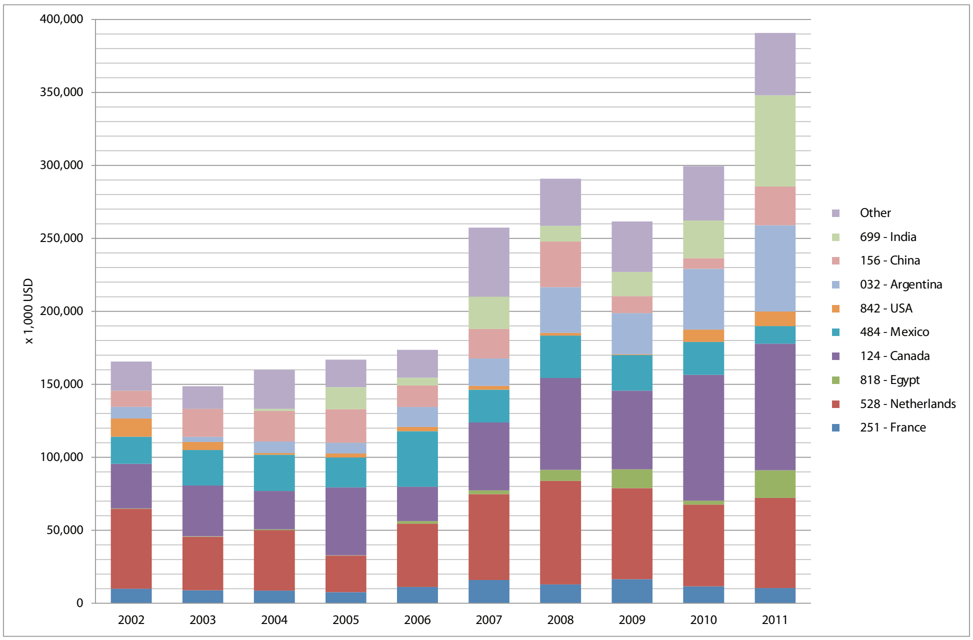


Figure 9.7. Import of vegetables in Algeria per country (2002-2011); Source: Comtrade.

About 70% of the import of vegetable products consist of dried leguminous vegetables, like kidney beans and lentils (see Figure 9.8.).

Import of vegetables more than doubled since 2002. The most important import vegetable products are:

- Dried lentils (USD 93.2 million, 2011)
- Dried kidney beans (USD 88 million, 2011)
- Dried chickpeas (USD 85.6 million, 2011)
- Seed potatoes (USD 80 million, 2011)
- Fresh garlic (USD 13.8 million, 2011).

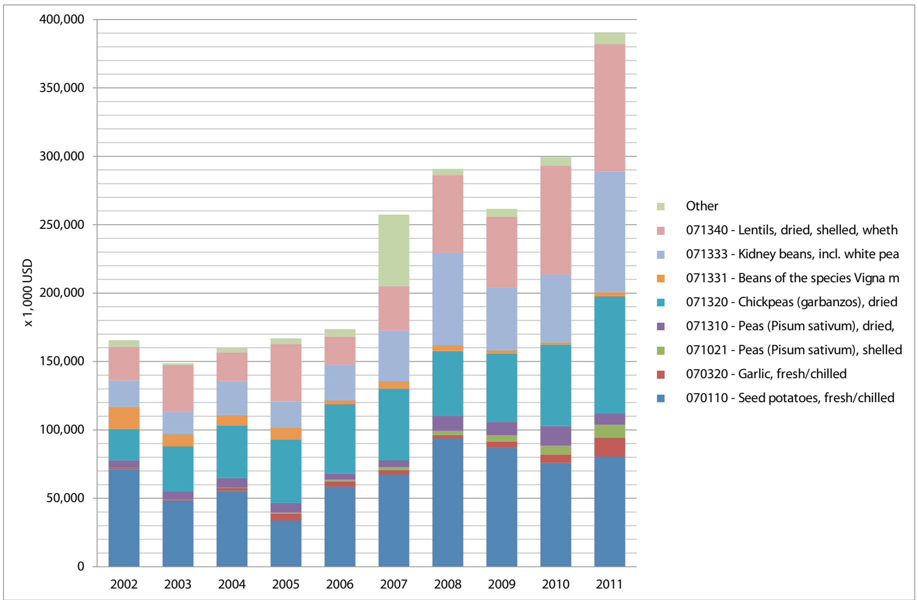


Figure 9.8. Imported vegetable products by Algeria 2002-2011; Source: Comtrade.

9.3.2 Production

The total production of vegetables in Algeria was 7.8 million tonnes in 2010 (FAOSTAT, see Figure 9.9.). The most important products in 2010 are potatoes (3.3 million tonnes), dry onions (1.1 million tonnes), watermelons (0.95 million tonnes) and tomatoes (0.58 million tonnes; open field and protected cultivation). The production is almost doubled between 2000 and 2010.

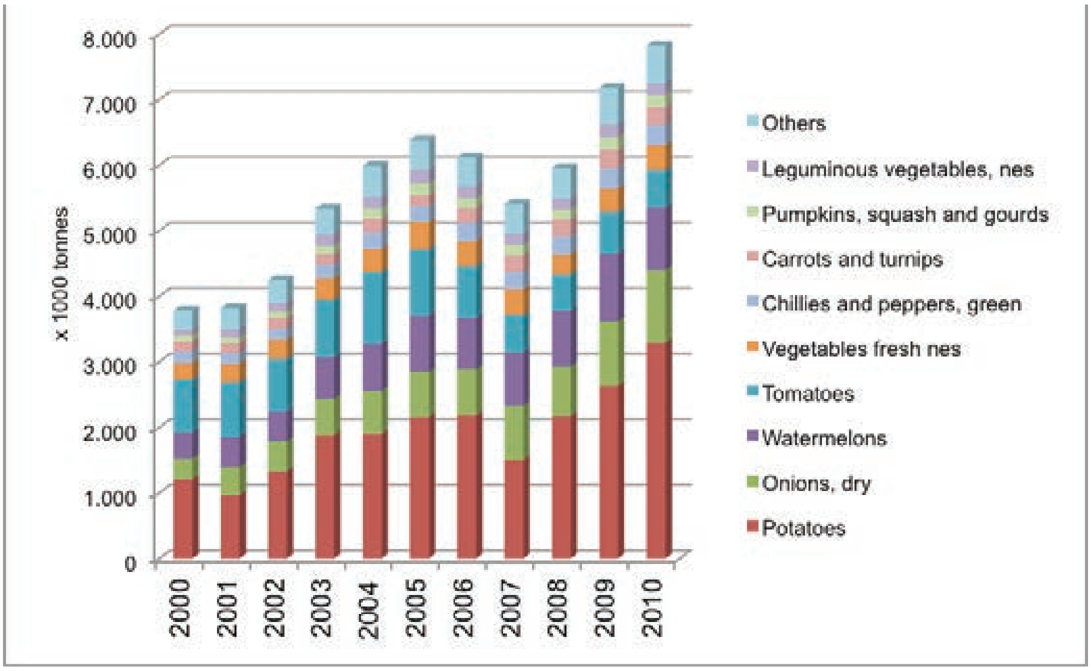


Figure 9.9. Production of vegetable products in Algeria (2000-2010) ; Source: FAOSTAT.

Between 2000 and 2005 the production of tomatoes increased from 0.82 million to more than 1 million tonnes. After 2005 the national tomato production decreased to 0.58 million tonnes in 2010. The smaller tomato production after 2005 was caused by a substantial lower harvested area in spite of a steadily increase of the yield per ha (in 2000: 18.6 ton/ha; in 2010: 30.3 ton/ha).

Potatoes are the largest Algerian agricultural product (in tonnes) before cow milk (fresh), but cow milk has the highest value (FAOSTAT). The value of potatoes in 2010 was 532 million USD. Production of dry onions and tomatoes are tenth and eleventh in agricultural value with 233 million USD and 214 million USD.

The total vegetable production in 2010 was realised on an area of 425,530 ha (see Figure 9.10.)

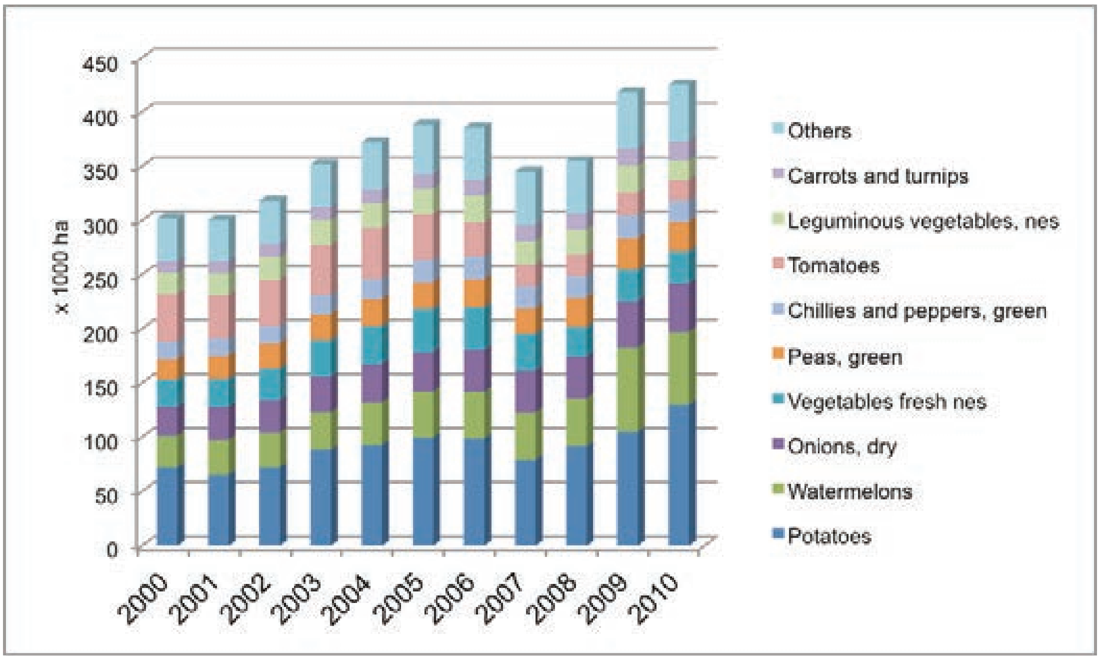


Figure 9.10. Harvested area of vegetable products in Algeria (2000-2010) ; Source: FAOSTAT.

The biggest area of harvested vegetable products concerns potatoes (130,000 ha), watermelons (67,100 ha) and dry onions (44,900 ha). The area of tomatoes (19,100 ha) is mainly open field production. The harvested area of tomatoes varied from 40,000 to 47,000 ha between 2000 and 2005. In 2006 the harvested area decreased to 31,000 ha and during 2007-2010 the area stabilized around 20,000 ha. The area of vegetable production has increased with ca. 40%, while the production has almost doubled. The yield (tonnes/ha) has also increased significantly.

9.3.3 Consumption

The consumption of vegetable products in Algeria was 6.8 million tonnes in 2009 (see Figure 9.11.) and was almost doubled compared to 2000. The most important consumed vegetables are potatoes, onions and tomatoes. These figures doesn't cover processed vegetables.

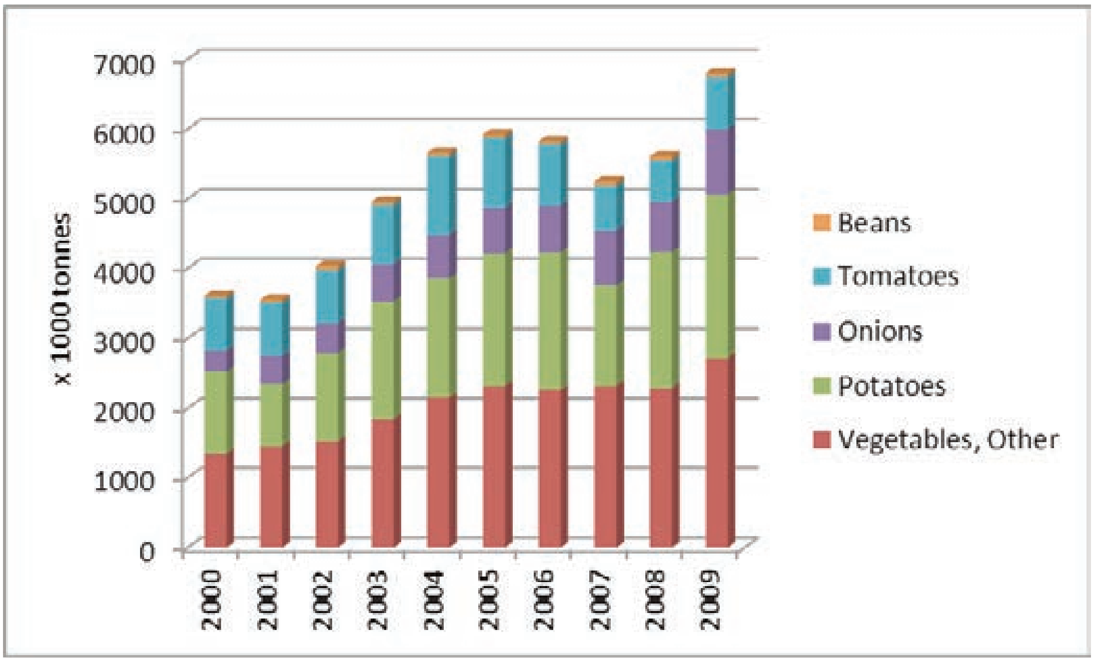


Figure 9.11. Consumption of vegetable products in Algeria (2000-2009) ; Source: FAOSTAT.

Remark:
The figures of vegetable production and consumption cannot be compared with the figures of export and import, because the type of vegetable products differs and due to the influence of the price component.

9.4 Marketing aspects of greenhouse vegetables

During the first trip in October 2012 a visit was made to the wholesale market in Algiers (E.MG.W.A) and a supermarket. A general impression has been acquired about the way fruit and vegetable products find their way from producer to consumer (see Report visit Algeria, BOCI project, 6-12 October 2012).
Some impressions are:

- Hardly no sorting or grading of products;
- Products are packaged in standard boxes (bulk);
- Hardly no cooled transport of products from producers to wholesale market;
- Limited (cooled) storage of products;
- Limited diversification of products on the consumer markets (local, store, supermarket, etc.).

These factors do not enable to maintain the best product quality and to obtain the best market position of fresh vegetable products.
In this part the marketing aspects of vegetables will be discussed and some recommendations will be given to improve the product quality and the product presentation in the horticultural supply chain.

A general image of the horticultural supply chain is illustrated in Figure 9.12.

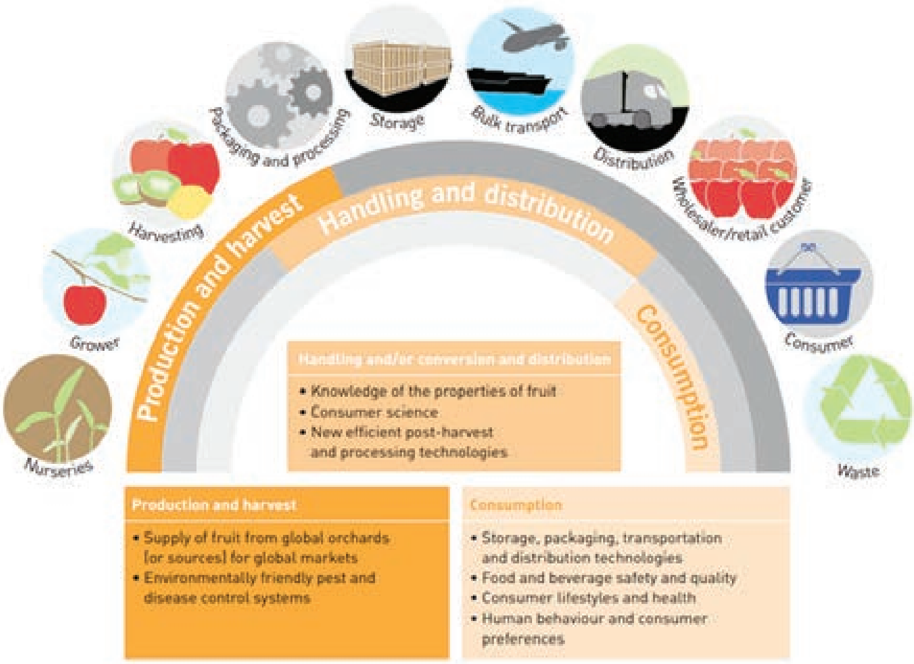


Figure 9.12. Horticultural supply chain, example for fruit (www.harvestingthesun.org).

Figure 9.12. describes the different phases of the horticultural supply chain, from nursery to the consumer. Not in all cases vegetable products will follow (completely) all the different phases. Most fresh vegetable products are not processed when they reach the consumer.

9.4.1 Current postharvest situation of vegetable products

In Algeria vegetable products of protected (and open field) cultivation are delivered to wholesale markets. The most important wholesale markets are located in the North of Algeria. The wholesale market are state organisations. The products are bought by commissioners and then being sold to retailers, grocery shops and other wholesale markets. The destination of the products is the domestic market. There is hardly no export (see 9.3.1). In addition also some import products are sold on the wholesale market.

Fresh vegetable products, like tomato, bell pepper, etc., have in common that they are perishable. The products have a limited shelf life and the products have to be transported in a short time to the different markets. The aim of all chain links is to maintain a good product quality in the chain and try to obtain the best market position.

The following points were noticed which can prohibit to achieve those goals:

- Hardly no sorting or grading of products: limited diversification on product quality (colour, shape, size, taste, etc.);
- Most products are packaged in uniform plastic boxes for transport and trading (see Figure 9.13.);
- Hardly no cooled transport from producers to wholesale market
- Limited (cooled) storage of products;
- Simple packaging methods/material: limited diversification of product presentation on the consumer markets.

Figure 9.13. Vegetable products packaged in standard boxes for the domestic market. (Photo Wageningen UR Greenhouse Horticulture)

Most vegetable products are packaged and transported in plastic boxes of 5-10 kg (bulk) as is shown in Figure 9.13. The products will mostly not be repacked for the different consumer markets (local, shop or retail). During transport vegetable products are not cooled as a consequence deterioration will occur. The products are hardly being stored in postharvest phase and also cooling of products is being done incidentally. However packaging and cooling is developing and mostly done by private companies.

After all there is a limited diversification of packaged products on the local market, shops and retail. Moreover the product quality in the shop is not always as it should be. Due to this the product presentation is sometimes rather poor.

9.4.2 Consequences of suboptimal conditions in the postharvest phase

The fact that conditions in the postharvest phase are not always fully optimal has a negative effect on the product quality and the product presentation. First of all loss of quality occurs through damages during harvesting, sorting and transport and due to deterioration after harvesting. The loss of quality implies both the exterior as well as the interior characteristics. Rough handling of the product will speed up the chance of damages. Deterioration of products starts directly after harvesting. This deterioration occurs faster at warm than at cool temperatures. The most effective way to prolong shelf life is to remove the product from direct sunlight after harvest. Postharvest life of products can be extended by controlling the climate conditions around products (temperature, humidity and air composition) during transport, storage and presentation (shop shelf). Secondly loss of quantity will occur through spoilage. If spoilage occurs the product cannot be sold to the consumer. Spoilage can have an biological (*e.g.* deterioration) and a physical background.

A limiting factor for obtaining the best market position is the small market segmentation of vegetable products. A limited diversification of product presentations - based on different product characteristics and/or different packaging methods - doesn't meet all the consumers preferences. Especially consumers of high-end products could be reached when more diversification of product presentations would be available.

In general suboptimal conditions in the postharvest phase will hamper realising high quantity and high quality of vegetable products. The consumers prices normally will be lower than under optimal conditions. As a consequence also the producers or growers prices of products will reach a lower level.

9.4.3 Improvement of product quality, product presentation and market position

In order to realize higher product quality, better product presentations and better market position of producers some solutions and improvements are suggested.

Product quality and product presentation

- First gentle handling of products during crop treatment, harvesting, sorting and transporting. The chance and the degree of damaged products can be minimalized. Deterioration and spoilage will decrease and fresh vegetable products will have a longer shelf life.
- Sorting or grading of products will enable the producer and retail to distinguish products with different quality levels, based on different product characteristics and/or packaging methods (see Figure 9.14.).

Figure 9.14. Sorting or grading of fruits (Photo ZESPRI International Ltd).

- A wide range of packaging can be used in preparing and sending products to the market. Packaging serves three functions: to preserve, protect and promote. Preserve extends the shelf life of products. The protect function prevents physical and disease damage during handling and transport. Package material can promote the product by having labels, logos, country origin, weight, size, etc. Good packaging reduces damages and deterioration and improves product presentation (see Figure 9.15.).

Figure 9.15. Sophisticated packaging method of sugar peas for export (www.harvestingthesun.org).

- An important improvement of the product quality in the supply chain can be realized by the so called 'cold chain'. The objective is to keep products at the appropriate low temperatures to reduce spoilage losses and to prevent contamination. A cold chain is vital when vegetable products are perishable and require a long process of transport and storage. The infrastructure of a cold chain generally consists of: pre-cooling facilities, cold storage facilities (see Figure 9.16.), refrigerated carriers, packaging, warehousing and information management systems (including traceability and tracking). (www.harvestingthesun.org)

Figure 9.16. Cold storage in Africa (www.harvestingthesun.org).

The optimal storage conditions for fruits and vegetables have been established and are listed for vegetables in Table 9.5.

Table 9.5. Examples of ideal storage conditions for vegetables

VEGETABLES	Temperature range (°C)	Relative humidity range (%)	Storage time
Asparagus	0 to 2.5	85 – 100	2 – 4 wks
Broccoli	0	90 – 100	1 – 2 wks
Celery	-0.5 to 0	90 – 100	3 – 10 days
Lettuce	0	90 – 100	4 – 16 wks
Mushroom	0	85 – 100	1 – 2 wks
Onion – dry	0	65 – 75	4 – 32 wks
Pea – green	-0.5 to 0	65 – 100	1 – 3 wks
Potato – eating	7 to 12	85 – 100	8 – 32 wks
Pumpkin	10 to 12	70 – 90	8 – 24 wks
Tomato – green	12 to 16	85 – 95	1 – 3 wks
Tomato – firm ripe	6 to 8	85 – 95	3 – 7 days

Source: www.harvestingthesun.org

It is expected that cold chains will improve shelf life and quality of fresh produce, stabilise prices in domestic markets, increase production surpluses and increases export opportunities.
However cold chains need to start at the farm/greenhouse with attention to harvest methods, removal from direct sunlight and pre-cooling and extend through the chain to the retail.

- The product presentation can be improved by grading of products and/or specific packaging. As mentioned under 'product quality' grading and good packaging enables producers and retailers to distinguish different product presentations for different market segments with adjusted price levels.

Market position of producers

- Producers can improve their market or competitive position by focussing on specific market segments. First the producer has to determine which market strategy he will choose: cost price or market focus. A cost price focus implies that a producer competes on the cost price for standard product by producing as cost efficient as possible. With the market focus the producer is looking at the needs from specific market segments and try to create added value to his product. Following that strategy the right choice of grading and packaging method have to be made.
  Different market segment can be distinguished:
    - o High quality product for high-end consumers (niche markets);
    - o Organic product;
    - o Export products: producers have to meet the standards of international retailers with respect to food/ product safety, hygiene, tracking and tracing, etc. (*e.g.* ISO, HACCP and GlobalGap).

GlobalGap implies voluntary standards for Good Agricultural Practice (GAP) during production and postharvest. GlobalGap provides a pre-farm gate standard for certification of farm inputs and covers all activities on the farm. It is a business-to-business label and is therefore not directly visible to consumers.

Traceability becomes more and more a necessity in order to react on breakdowns in the supply chain as a consequence of degraded food or contamination with diseases or undesirable substances. The point of failure has to be traced as fast as possible.

- Another possibility to improve the market position of (small) growers is to cooperate with other (small) growers (horizontal cooperation). Analogous to European growers of protected vegetables Algerian growers can cooperate in Producer Organizations. In a Producer Organization growers can make agreements on quality standards, packaging, purchasing, etc. As a result of the larger volume of united produce the Producer Organization can be an interesting partner for the retail and can even become a preferred supplier. This will enlarge the continuation of the greenhouse farm.
- A step further is that growers and/or Producer Organizations cooperate with other chain links - seed industry, wholesale and/or retail - in a closed chain (vertical cooperation). With a closed chain the parties can control the production and marketing of products in order to focus on specific market segments and/or to prevent overproduction and lower pricing. This development implies for all partners to enter into an agreement and to stick to the agreement.

The ultimate goal is that the producer will receive a better price for his product and/or create a solid position in order to maintain or to improve the profitability of his greenhouse production system.

9.4.4 Supply chain cost structure

Although producers can improve their competitive position, the market power is however limited. Especially when commodity products are produced. In case of special products for niche markets producers do have some influence on the product price. In Figure 9.17. an example is shown about the cost structure of fruit in the supply chain. Figure 9.17. shows that the consumer price is 5 times the producer price and the retail margin is about 25%. In general the multiplier between consumer price and producer price of horticultural products is 3-5. The net profit margins differ per chain link. In general the net profit margin is the highest in the seed industry and retail (ca. 15%), followed by supply (ca. 8.5%) and trade/logistics (ca. 5%). The production link shows the lowest net profit margin (ca. 0%; range between -2% and +2%). Important reason for the low net profit margin on producer level is the great number of producers and the fact that they are price taker. In the seed industry and retail only a limited number of (international) companies are involved and they are price makers. As a consequence there market power is much stronger.

Producers of greenhouse vegetables have to make more efforts to improve their market position.

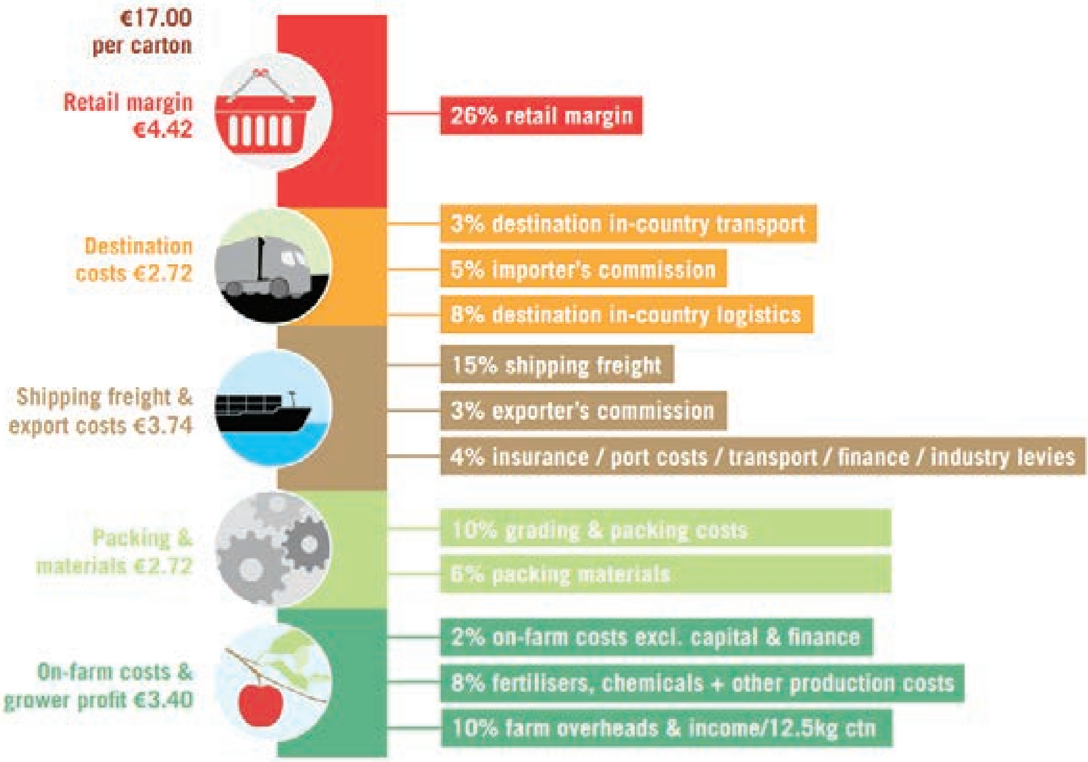


Figure 9.17. Supply chain costs structure of apples produced in Southern hemisphere and traded on the European market (www.harvestingthesun.nl).

9.4.5 Conclusions

The postharvest situation and marketing of greenhouse vegetable products in Algeria is not yet optimal. Sorting and grading is implemented at a low profile, packaging is mostly simple and cooling of products from grower level to retail/ consumer level hardly takes place. As a consequence there is small diversification of products and product presentations. There are different opportunities to improve product quality and product presentation, such as: reducing damaged products during cultivation, harvesting and transport; sorting and grading of products; good packaging methods (preserving, protecting and promoting) and implementation of the 'cold chain' (cooling facilities at farm and storage level, and refrigerated transport).
The market position of producers can also be improved, but they are modest (producers are price taker). Producers can focus on specific market segments (domestic and international markets) or can cooperate in a horizontal way (producer group/organization) or in a vertical way (closed chain structure). Certification of production can help the grower to distinguish from other producers.

10 Project goals evaluation

Evaluation project goals as mentioned in chapter 1.1:

- This study shows the potentials of Algerian greenhouse industry and the role Dutch companies can play. The need for knowledge to increase the production capacity is large. Both, technically (blue print of greenhouses) and labour skills (how to manage new technologies) are required.
- Several projects focussed on the development of Algerian horticulture (G2G, Boci) and will be continued in SMASH. In all projects there is close collaboration between government, research and advisory.
- Active participation took place, starting in G2G, with Dr Amrar, director of ITCMI, and governmental representative who showed the willingness of the Algerian government to modernize greenhouse horticulture and the transfer of knowledge, which can hopefully be continued in SMASH.
- The proposed roadmap evaluated in the creation of an Algerian Dutch consortium realizing (part of) the project SMASH which is approved June 2013.
- Activities described have been executed, such as analysing the structure of the Algerian greenhouse industry, improved design of new greenhouse concepts, economic feasibility. Transfer of knowledge was realized by two workshops in Algiers which were visited each by more than 60 participants.
- Three missions took place to inquire the position of the Algerian horticulture but also to meet representatives of Ministries, Governmental bodies and private companies. Results are all summarized in this report and cooperation is organised in the project SMASH.

11 Conclusions

The current report gives an extensive overview of the greenhouse structure in Algeria and its potentials at the moment greenhouses will be improved of newly built. Estimations and calculations have been made by the Wageningen UR adaptive greenhouse approach: use of local climate data and experience to present improvements for local greenhouses. Type of greenhouse, cultivation system and economics and marketing were subject of investigation.

Type of greenhouse
Two regions were investigated: the coastal zone with a Mediterranean climate (Algiers) and the sub-desert region of Biskra, south of the Rif mountains, gateway to the Sahara. Both have a substantial greenhouse area:

- Compared to The Netherlands (3.8 GJ/m^2/yr) radiation in Algiers (6.5 GJ/m^2/yr) and Biskra (7.2 GJ/m^2/yr) is much higher and, consequently, the potential yield is much higher;
- High temperatures in summer decrease the growing season dramatically. In Biskra frequently temperatures arise above 35 °C realizing a much shorter growing season compared to Algiers;
- Precipitation in Algiers is on average 550 mm/yr in the last decades; in Biskra it is supposed less than 200 mm, although accurate data fail. Although rain mainly falls in peaks it is quite well possible to collect rainwater and to cover the water need in a season for 75 - 85% with a 1000 m^3/ha 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;
- In Biskra wind blows mainly from Northwest or southeast, making that the principal direction of the single tunnel. In Algiers there is no dominating wind direction;
- Wind speed is mostly more than 2 m/s in day time which is sufficient for natural ventilation;
- In both areas heating can be useful as minimum temperature drops frequently below 10 °C, while 15 °C can be seen as the lowest temperature.

Looking to the present situations there are single span tunnels, Canarian greenhouses and multispan tunnels.
The single span tunnel has:

- Limited ventilation (3% in front and back door) which 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 that should be a thermic film with high transmission (>75%) realizing diffuse light in the tunnel and 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, much more humid, pad & fan cooling is not recommended;
- Shading in Biskra with a sand/mud mixture decrease light much more than temperature and should be minimized. Dosing in steps and measuring quantity is recommended;
- 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 in favour of the multispan tunnel:

- Low outside relative humidity and precipitation. 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.

The multispan tunnel has a:

- Ventilation capacity (currently between 10 and 15%) should be increased to around 40%. Openings are covered with insect nets mainly against Tuta absoluta.
- Cover of glass: multispan covered with a plastic film is much cheaper with lower yields and slightly lower revenues,

which will function quite well. Maintenance and repair are easier to realize for a plastic cover than for glass. If capacity building is well organized to achieve the high potential yield to balance high investments glass can be used. Lifespan of a glass house (10 yrs) is much longer and in that time a plastic cover has to be replaced more frequently (3-4x).

- Shading by a movable screen (30% open, 70% closed strips) is recommended;
- Heating is needed and as a pipe/rail system it can be used for internal transport too. If heating is available via a burner, CO_2 application can take place too, especially when a buffer for heat storage during the day and usage at night of 150-200 m^3/ha 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.

Cultivation

The amount of rainwater which can be collected from the cover of the greenhouses is substantial (75 - 90%) in the Algerian climate with a rainfall of 500-600 mm per year (Algiers). For the region Biskra the need for rainwater collection is much less because of the little rainfall (< 250 mm; no details available) This type of water is of excellent quality and is a major demand for soilless growing methods. A reservoir of 1000 m^3/ha 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 a similar way. 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. Generally registration of crop and labour details can be improved.

Economics

Economic calculations point out that improved ventilation with large windows in both a single tunnel as well as in the multispan tunnel show the best extra net 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 requires an extra investment in case of new establishment.

The multispan tunnel design with large windows, pad & fan system and heating/CO_2 realizes also good financial results and are similar to the multispan tunnel with large windows. In Biskra the extra net result is even higher than the multi-tunnel with large windows. This multispan tunnel design requires a high extra investment (ca. 2400 DA/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 deteriorates the financial results, but show better financial results than the simulated reference tunnel system. Nevertheless the pad & fan system appear to show better financial results in the (dry) Biskra region than in the (humid) Algiers region in both the single tunnel as well as the multispan tunnel greenhouse.

Marketing

The postharvest situation and marketing of greenhouse vegetable products in Algeria is not yet optimal. Sorting and grading is implemented at a low profile, packaging is mostly simple and cooling of products from grower level to retail/ consumer level hardly takes place. To improve the market position of Algerian growers different opportunities are available, because:

- Hardly any grading, packing and cooling takes place;
- Product diversification does not take place, there is no export. However the expectation is that with diversification it is possible to get higher prices for the produce;
- Implementation of the 'cold chain' (cooling facilities at farm and storage level, and refrigerated transport).

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Annex I Climate data.

This appendix shows bar plots with monthly average values for temperature, humidity and global radiation for both Algiers as well as Biskra.

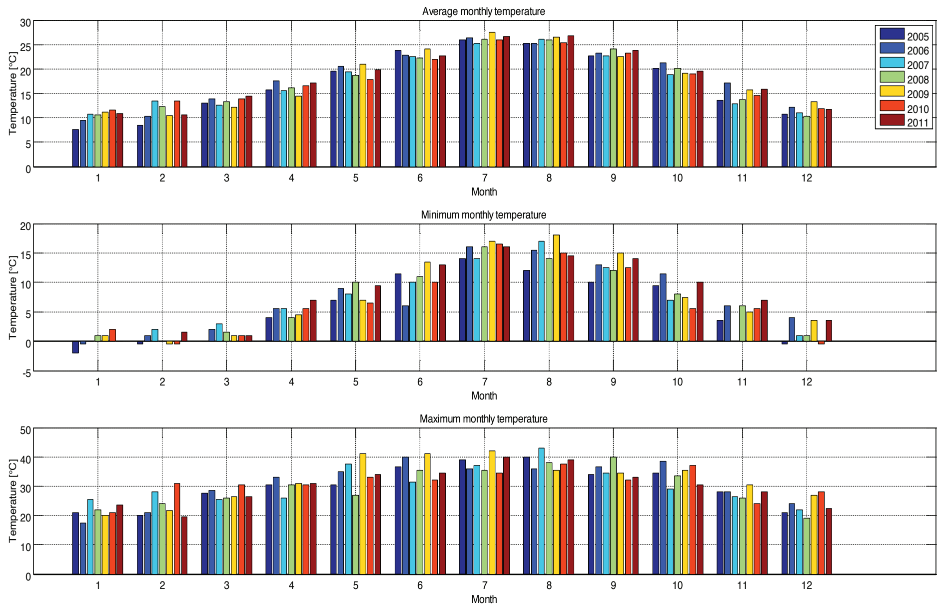


Figure A1 Average, mean and maximum monthly temperatures month in Algiers over the past 7 years.

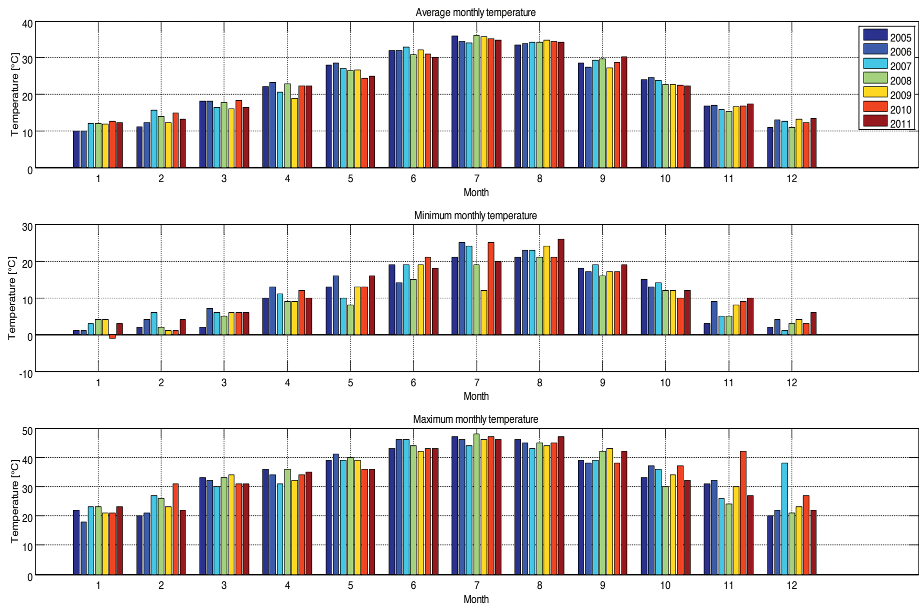
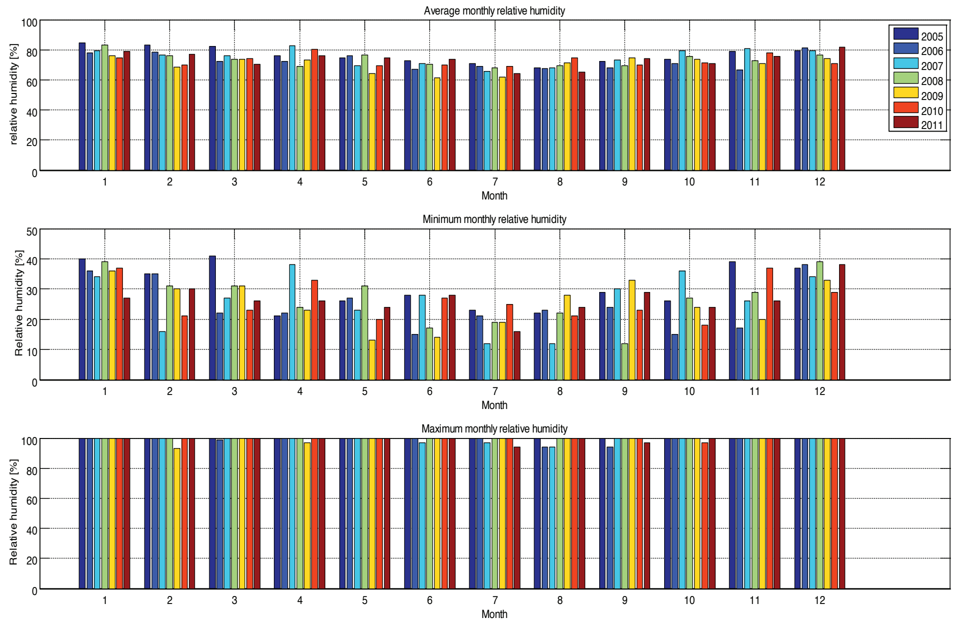


Figure A2 Average, mean and maximum monthly temperatures in Biskra over the past 7 years



Figuur 1. Figure A3 Average, mean and maximum monthly relative humidity in Algiers over the past 7 years

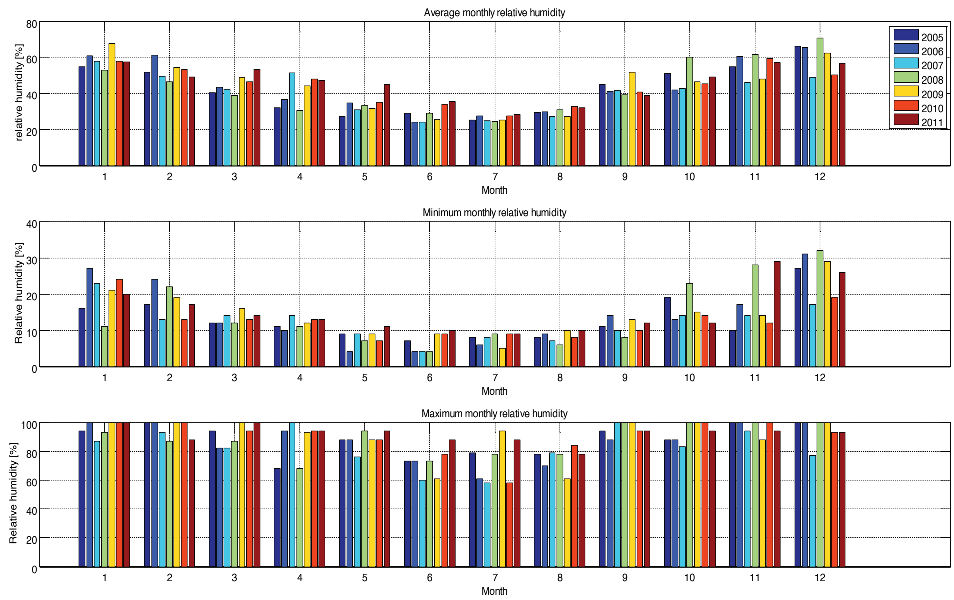


Figure A4 Average, mean and maximum monthly relative humidity in Biskra over the past 7 years

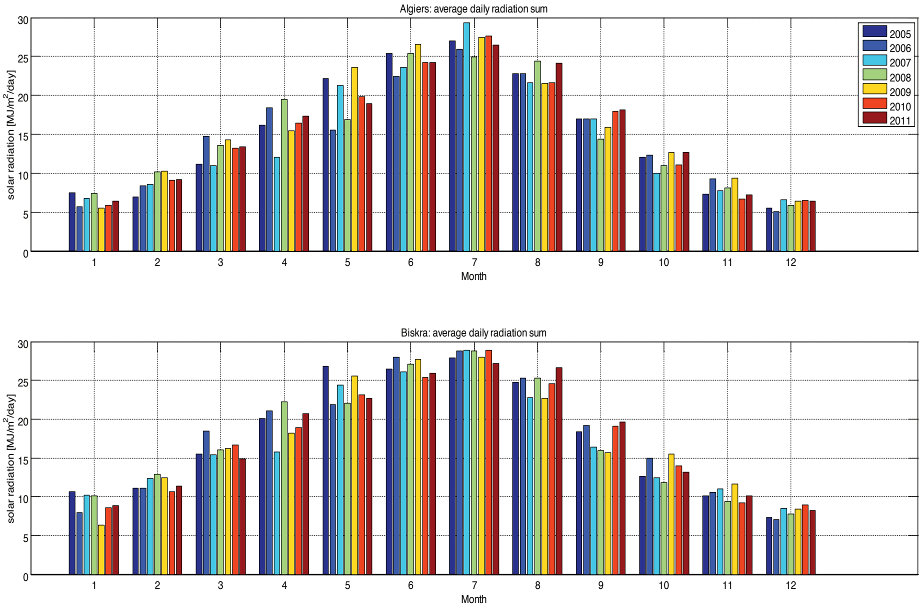


Figure A5 Daily radiation sums for Algiers and Biskra over the past 7 years

Annex II Settings for the KASPRO simulations for single span tunnels.

The climate inside a tunnel is simulated with KASPRO. Originally, KASPRO is intended for large, multi span greenhouses. The model inputs are adjusted such that the model give credible estimates for the climate inside the tunnels. Unfortunately, no measured data is available for calibration of the model. Therefore, the simulation data can only be used to compare the effects of the different measures. For example, the effect of shading on the climate can be studied between different shading levels. However, the results should not be compared to the simulation results for multi-span greenhouses.

Tunnel dimensions: 8x50x3.2m high
The air content is approximately: $20m^2$ x 50m = $1000m^3$ (=$2.5m^3/m^2$). The size of the opening a the beginning and end of the tunnel varies; we will use 8m2 in our simulations. Some tunnels have additional openings in the roof, spread over the length of the tunnel. The effect of these openings cannot be studied with KASPRO, but are studied with a CFD model instead.
surface: 8*50 = $400m^2$

KASPRO uses the following settings to mimic the behaviour of the single span tunnel:
gutter height: 1.5m
roofslope: 30°
width: 8m.
The window fraction is 16m2 window/400m2 greenhouse = 0.04. To mimic this in KASPRO we have used a *windowlength* of 1m, a *windowheight* of 0.1m and a *windownumber* of 0.4window/m2 greenhouse, resulting in 1*0.1*0.4 = $0.04m^2_{window}/m^2_{greenhouse}$
No heating system
planting date: 15th of September. End of season: 1st of May for Biskra and 1st of June for Algiers.
Heating setpoint: 16 °C at night, 20 °C during day.
Ventilation setpoint: dT=2 °C, light intensity setpoint raise = 3 °C.
(thus, the windows open during daytime at 20+2+3=25 °C)

Annex III Financial overview of improved single tunnel (DA/m^2).

Single tunnel	**Biskra**			**Algiers**		
Economic results (DA/m2)	reference	large windows	large windows + pad&fan	reference	large windows	large windows + pad&fan
Simulation results						
production tomato [kg/m^2/ year]	12	20	29	26	36	41
price tomato [DA/kg]	41.5	41.5	41.5	40.0	40.0	40.0
Revenues	498	830	1204	1040	1440	1640
Variable cost						
energy (& CO_2)	0	0	35	0	0	35
labour	45	74	108	97	134	153
water & nutrients (& recirculation)	106	123	144	120	158	169
others (plants, chemicals, substrate, packaging etc.)	150	154	159	157	162	165
total variable costs	300	352	445	374	454	522
Investments						
greenhouse construction & covering	880	985	985	880	985	985
other installation costs (heating, CO_2, screening, climate control etc.)	200	200	1400	200	200	1400
Irrigation system and rain water storage	220	220	220	220	220	220
additional installation costs (transport, packaging area, maschinery etc.)	138	138	216	138	138	216
Total investment (excl. ground)	1438	1543	2821	1438	1543	2821
Yearly total cost for production means (incl. depreciation and ground)	*217*	*228*	*593*	*217*	*228*	*593*
Net result	-19	251	166	450	758	526

Annex IV Financial overview of improved multispan tunnel (DA/m²).

	Biskra				**Algiers**			
Economic results (DA/m2)	Refe-rence	large win-dow	large win-dows + pad&fan	large window + pad&fan + heating &CO_2	Refe-rence	large win-dow	large win-dow + pad &fan	large window + pad& fan+ heating &CO_2
Benefits								
production tomato [kg/ m^2/year]	17	24	33	49	28	37	41	60
price tomato [DA/kg]	41.5	41.5	41.5	41.5	40.0	40.0	40.0	40.0
Revenues	706	996	1370	2034	1120	1480	1640	2400
Variable cost								
energy (& CO_2)	0	0	35	275	0	0	35	298
labour	63	89	123	182	104	138	153	223
water & nutrients (& recirculation)	117	132	152	187	141	160	169	211
others (plants, chemicals, substrate, packaging etc.)	153	156	161	169	158	163	165	174
Total variable costs	333	377	470	814	403	461	522	907
Investments								
greenhouse construction & covering	2700	2700	2700	2700	2700	2700	2700	2700
other installation costs (heating, CO_2, screening, climate control etc.)	1010	1010	2210	3405	1010	1010	2210	3405
Irrigation system and rain water storage	440	440	440	440	440	440	440	440
additional installation costs (transport, packaging area, maschinery etc.)	579	579	579	579	579	579	579	579
Total investment (excl. ground)	4729	4729	5929	7124	4729	4729	5929	7124
Yearly total cost for production means (incl. depreciation and ground)	*695*	*695*	*1037*	*1177*	*695*	*695*	*1037*	*1177*
Net result	-322	-76	-138	43	22	325	82	316

Ministerie van Economische Zaken

Projectnummer: 3242155300