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Greenhouse Technological Packages for High-Quality Crop Production

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Abstract

In the last decades, protected cultivation has spread widely around the world. The globalisation of the markets has increased the competitiveness, highlighting the need for high quality of the produce. Site selection is a key aspect for profitable greenhouse production, specifically for the climate conditions that influence the cost and quality of the horticultural commodities, but also for the distance to the markets. The local microclimate conditions influence the strategic election of the "greenhouse technological package" (structure and equipment) whose technical level will determine the future possibilities of climate control, influencing the yield and quality of the produce. A wide variety of greenhouse technological packages are nowadays available, from simple plastichouses to very sophisticated glasshouses. Information on the growing strategies that can be afforded to supply the markets with high-quality vegetables yearround and on the greenhouse packages commonly used for that purpose are included, with special reference to the Mediterranean basin.

INTRODUCTION

In the last decades, the greenhouse industry has spread widely around the world. There are two basic "greenhouse agrosystems" (Wittwer and Castilla, 1995). One type is the sophisticated and highly controlled "Northern greenhouse agrosystem", typical of the high latitude areas of Europe and North America, that developed first in these colder climates because of the obvious inability to grow plants outdoors in freezing weather (Albright, 2002). The other type provides minimal climate control, enabling the plants to survive and produce an economical yield (Enoch, 1986). The design of a greenhouse agrosystem, in between these two extreme types, can vary greatly depending on whether it is located in a desert, the tropics or in a temperate region (Jensen, 2002).

Economic competitiveness of greenhouses in tropical, subtropical and temperate regions (compared to outdoor production) may be significantly less than in high latitude areas, where glasshouses predominate and, thereby, structures and environment modification systems may not be economical unless they are simple and require little energy input (Albright, 2002).

The "greenhouse effect" of increasing the air temperature, that traditionally was the basic objective of protected cultivation in greenhouses, in some cases is just limited to very short periods of low air temperatures, as it is frequent in temperate, subtropical or tropical areas. In these regions, the "shading effect" (reduction of solar radiation) during the high radiation season, or the "windbreak effect", provided by the greenhouse, are often much more important than the "greenhouse effect" (Castilla, 2005).

In arid or desert regions, the isolation provided by the greenhouse from the outside environment (very hot and dry), rising the air humidity and limiting temperatures in a well watered crop, induced to describe a sort of "oasis effect" (Sirjacobs, 1988). In very rainy tropical regions, a sort of "umbrella effect" prevails in the greenhouses (named rainshelters), as the basic objective of protected cultivation is avoiding the rain that hinders normal growing due to flooding (Garnaud, 1987).

Cladding the greenhouses with screens (nets), instead of plastic films, is extending in recent years in very mild temperature areas (of low latitude) or periods (in medium latitudes

This paper presents a general outlook on the growing strategies that can be afforded to supply the markets with high-quality vegetables year-round and on the "greenhouse technological packages" commonly used for that purpose, with special reference to the Mediterranean basin. Information on the influence of the greenhouse climate on quality, focused on the tomato crop, is included.

MARKETS

Market Demands

The present consumer is demanding, unfaithful, well informed, and very interested in quality; buying habits have evolved, influenced by the new socio-economic characteristics of the markets, as it was stated years ago by Preneux (1993).

Horticultural products have to be produced safely, even within socially accepted labour conditions (van Uffelen et al., 2000) and way of production (Ammerlaan et al., 2000). The traceabilitiy of the produce is becoming a necessary must for the production, in order to provide the consumer with the required security about the way of producing. Growers have to produce their high quality commodities in an environment conscious, labour safe and a hygienic way and be able to demonstrate this, to meet the customer's demands (van Uffelen et al., 2000). The general image of the greenhouse as a "clean" and environmental-friendly way of production is being promoted.

The greenhouse industry has responded with a more highly focused market-driven approach to production (Sullivan et al., 1999), translating the specifications of the market into production standards. Nowadays, it is a common practice, in contract-based production between supermarket chains and large producers or co-operatives, to include in the contract detailed protocols to be followed by growers for the sustainable production of safe and nutritious vegetables. The year-round vegetable supply demanded by the market and the enormous size of the supermarket chains in developed countries (the target of most exports) emphasize the need for grouping growers into large co-operative marketing organisations (Pardossi et al., 2004).

The distance from the markets, in export-focused production, appreciably increases transportation costs (Castilla et al., 2004) and limits the competitiveness of those production areas that are distant from their target markets, as Mexico in North America or the Mediterranean basin in Europe. Differences in transportation costs between European and African countries within the Mediterranean area can offset the potential advantages of southern countries (for their lower production costs, especially labour), when exporting to Europe (Castilla, 2002).

Year-Round Supply of High Quality Products

In cold high latitude areas, the introduction of supplementary heating and CO_2 enrichment in the winter, high light transmission in the glasshouse structure and high light interception in the canopy structure as well as the soilless culture made year-round cropping possible (Ho, 2002). Product quality around the winter solstice, in some cases, can be insufficient due to low solar radiation. Overcoming this problem sustains the use of artificial supplemental lighting in the greenhouse industry of high latitude countries (Papadopoulos et al., 2002).

Year-round plant production outdoors in tropical and subtropical regions can suffer quality disadvantages for at least part of the year. Rainy seasons, in particular, create significant problems (Albright, 2002), promoting protected cultivation.

Some greenhouse crops in mild winter climates cannot be grown all year-round and their yield does not fulfil the quality standards, because of inadequate climatic conditions prevailing in the rudimentary shelters used as greenhouses (Baille, 2001). The growing period is often limited to 6 or 7 months per year, due to the lack of a proper climate control (cooling in late spring and summer, heating in winter). Generally, most plastic greenhouses operate on a seasonal basis, rather than year-round (Jensen, 2002).

Environmental Impact

Along the last years, in developed countries the society becomes increasingly concerned with the environment and a general trend for reduced use of energy, pesticides, chemicals and waste emerged (van Uffelen et al., 2000). For instance, general legislation determined that growers had to limit the emission of polluting agents in the European Union (van Os and Benoit, 1999). And relevant changes in the growing practices and cultural techniques have been widely adopted.

Limiting the environmental impact of protected culture must also include the saving of natural resources and the reduction of wastes. Different authors have reported that closed soilless culture system can reach similar and even better yield and fruit quality than the conventional open soilless system (Papadopoulos et al., 2001; Schnitzler and Gruda, 2003).

The recycling of waste became very important, as the re-use of plastic is contributing to the productivity and energy efficiency increases, as it was pointed years ago (Baker et al., 2000). The recycling of plastics must be a primary objective in those emerging countries that have not yet considered it. Nowadays, in the Almeria area (Spain), over 95% of the greenhouse plastic cover residues are recycled.

The lower energy inputs of simple climate control methods in Mediterranean greenhouses, for example whitewashing as compared with mechanical ventilation, contribute to reduced environmental impact (Anton et al., 2006). Recent data, comparing the sustainability of the greenhouse produce in Spain and the Netherlands, show that primary fuel consumption for cultivation and transport purposes per kg of tomato, sweet pepper and cucumber is estimated to be 13, 14-17 and 9 times greater, respectively, in the Netherlands (Van der Velden et al., 2004). Though there is limited information comparing the global environmental impact of different greenhouse types, preliminary studies point out that plastic greenhouses appear as more eco-compatible than glasshouses (Russo and ScarasciaMugnozza, 2005).

QUALITY

General Aspects

Quality is a combination of attributes, properties or characteristics that give each commodity value in terms of intended use. Quality components are appearance, textural, flavour and nutritional quality factors and the relative importance of each quality component depends upon the commodity or the product and how it is utilised, and varies among producers, handlers and consumers (Kader, 2000).

The setting up of integral quality management systems has been widely established, in order to emphasize the quality and differentiation strategies of greenhouse production.

Vegetable Quality

The quality attributes of vegetables vary depending on the related species. Quality norms for fruit and vegetables are generally based on external quality and critical concentrations of pesticides and nitrate (Schnitzler and Gruda, 2003). Due to the big number of greenhouse vegetable products, this short outlook on quality is limited to the tomato, the leading greenhouse vegetable crop.

Tomato fruit quality is mostly related to its general appearance, including color, shape, size, firmness and absence of defects, as well as to its taste and flavor, ripening behavior, shelf life and shipping resistance (Grierson and Kader, 1986; Nisen et al., 1990). Tomato fruit dry matter content, that varies normally between 5.0 and 7.5% fresh weight, is inversely related to fruit size and positively related to total sugar content (Bertin et al., 2000). About 60-65% of total fruit dry matter consists of reducing sugars, mainly glucose and fructose, and organic acids, mostly citric and malic acids, which have a large influence on the taste and overall flavour of tomato (Stevens, 1986).

The sugar and acids contents and their interactions determine tomato flavour (Grierson and Kader, 1986). In spite of the cultivars variability, low pH values (below 4.4) and sugar contents over 4-4.5% are required for good tomato taste and flavour (Nisen et al., 1990).

Low radiation and temperature values reduce tomato fruit dry matter content, therefore affecting the quality, due to insufficient sugar content (Grierson and Kader, 1986). High temperatures limit tomato fruit acidity, negatively influencing taste and flavour (Castilla, 1995).

High solar radiation has a positive effect on the accumulation of major antioxidant components of tomato (Toor et al., 2006). The tomato fruit is the principal dietary source of lycopene, an effective antioxidant that cannot be synthesized in the human body (Wu et al., 2004). The protective benefits of the antioxidant compounds are, in part, due to their ability to quench free radicals and, thus, prevent abnormal oxidative changes in the human body (Toor et al., 2006).

Fruit quality can be significantly enhanced when plants are grown under moderate water stress conditions, in terms of TSS (total soluble solids) and lycopene in the fruit with no significant yield loss (Wu et al., 2004). Adjusting the salinity of the nutrient solution allows growers to modify water availability to the crop and hence improve tomato fruit quality. At some point, however increases in salinity limit marketable yield (Dorais et al., 2001). A proper irrigation regime can limit the negative influence induced by high salinity of the irrigation water on yield, still keeping the beneficial effect on fruit quality (Restuccia et al., 2003).

During the high radiation season, fogging and mobile shading can provide similar marketable yields of a tomato crop when good quality water is used. However, if water of moderate salinity is used, mobile shading allows higher commercial yields, mainly due to its effect on the reduction of BER (blossom end rot) and thus on fruit quality (Lorenzo et al., 2004).

Climate Control, Yield and Quality

The greenhouse structure and covering have a determinant effect on the microclimate, due to their influence on the radiation conditions (quantity and quality) and on the other microclimate parameters. As the climatic conditions for high yield are not always the same as for fruit quality, they should be optimised for both yield and quality (Ho, 2002).

Tomatoes produced in a cold greenhouse during winter and early spring are characterized by values of dry matter, titratable acid and reducing sugars, lower than those usually reported for fruits produced in open field or in heated greenhouse (Castilla and Fereres, 1990; La Malfa and Leonardi, 1992).

In the United Kingdom, the important contribution of environmental control in glasshouse tomato production can be seen clearly from the comparisons between the cold and heated house productions and between the high-tech growers and low-tech growers. In 2001, the annual yield in the heated house was around 4 times higher than that of the cold houses (i.e. 120 t ha^{-1}) and the best national yield (i.e. 670 t ha^{-1}) was still about 50% higher than the average national yield (Ho, 2002).

Salinity

The negative effect of salinity can be mitigated when greenhouse VPD (vapour pressure deficit) is constrained at a moderate level (Montero, 2006). In general, manipulating the indoor climate, such as humidity, temperature and ambient CO_2 level, may offset the negative effect of high salinity on yield and fruit quality such as BER (Stanghellini et al., 1998; Dorais et al., 2001)

Light

Light transmission enhancement in greenhouses can be reached modifying roof slopes and orientation (Castilla and Lopez-Galvez, 1994; Castilla et al., 2000). The characteristics of the cladding material determine the quality of the light transmitted into the greenhouse. The wide assortment of plastic films offers the grower the possibility of improving radiation transmission both, quantitatively and qualitatively (Baille, 1999; Hoffman and Waaisenberg, 2002).

Tomato fruits harvested from April onwards in the Mediterranean area, ripened under conditions of solar radiation of more than 13 MJ m^{-2} d^{-1} reached, at least for reducing sugars and titratable acidity, values near to those considered suitable for taste and flavour of table tomatoes (La Malfa and Leonardi, 1992).

In northern regions, there is a period of two to three months (December until February) during which practically no greenhouse vegetables are produced without artificial lighting (Papadopoulos et al., 2002). Artificial light is generally used from October to March. In these northern areas, the main reasons for the use of supplemental lighting are not only to increase crop production and product quality, especially in winter, but also more to ensure a year-round production and quality level which meets market demands (Marcelis et al., 2002).

Humidity

The influence of air humidity on plant and water relations affects growth and, consequently, yield. Besides the need of controlling temperature, humidity regulation is an important and difficult task, especially in winter, because high levels of humidity can lead to yield losses, especially in the tomato crop (Holder and Cockshull, 1990), due to physiological disorders. Low VPD reduces occurrence of BER but increases fruit cracking (Bertin et al., 2000)

High values of VPD are known to alter the water balance by decoupling the transpirational flux and the roots water uptake (Grange and Hand, 1987), thus leading to water deficits that increase the occurrence of physiological disorders (Yao et al., 2000).

Temperature

The growth, yield and quality of most greenhouse fruit vegetable crops (excluding leafy crops) are, normally, affected when temperatures are below 12ºC or exceed 30ºC (Castilla, 2005), varying their optimal temperature ranges between 22 and 28ºC in daylight hours and from 15 to 20ºC at night (Tesi, 2001).

Davies and Hobson (1981) found that temperatures between 16 and 21ºC favour lycopene synthesis, whereas temperatures above 30ºC inhibit lycopene synthesis and the tomato fruit remains yellow rather than red. Poor fruit set occurs at low and high temperatures, also affecting tomato quality. In the summer season, a good cooling management of the greenhouse during peak hours can minimize the negative effect of high temperature on lycopene and ascorbic acid of the tomato fruit (Toor et al., 2006).

1. Heating. The problem of low temperatures during winter can be solved by some heat supply to the greenhouse during the critical periods. The problem is not technical, as it is easy to heat an enclosure, but economical, as the investment and the operating cost are relatively high (Bartzanas et al., 2005).

Air heaters are generally used as the primary heating sources in greenhouse areas where the heating needs are low. Their main advantages are to promptly respond to control changes in temperature and their initial lower cost, while the disadvantage is their lower energy efficiency (Bartzanas et al., 2005).

In temperate areas of relevant winter heating requirements, the use of a mixed heating system (plastic heating pipes plus air heater) is favourable, as compared with a single heating system (only plastic heating pipes), since the use of the air heater improves the control of both air temperature and humidity, particularly by keeping the inside dew temperature lower than the cover temperature and preventing the occurrence of condensation on the plastic films (Bartzanas et al., 2005).

2. Cooling. Diverse methods for cooling the greenhouse are available in order to reach more adequate conditions for plant growth. In tropical, subtropical and temperate regions, natural ventilation is the common method. However, natural ventilation is frequently insufficient for extracting the excess energy in high radiation periods and other cooling methods are used, complementing or substituting it.

When natural ventilation is insufficient to avoid plant stresses, the alternatives are: mechanical ventilation, shading nets (inside or outside the greenhouse), whitewashing, evaporative cooling (fan-and-pan or fogging) or a combination of them.

In mild temperature areas located close to the sea, where open air humidity and temperature are normally near optimum levels for most vegetable crops, greenhouse climate can be acceptable in most of the growing season provided that ventilation is good enough (Montero, 2006). However, special attention should be given to improving ventilation in these coastal greenhouses before contemplating investments in more complex technology such as evaporative cooling systems. This is not the case in arid and semiarid areas, where evaporative cooling is a pre-requisite for extending the growing season during the hottest months (Montero, 2006).

Greenhouse shading limits the irradiance and, consequently, the heat load and air temperature. Any decrease of light might be expected to decrease crop productivity (Gonzalez-Real and Baille, 2006). The reduction of light, due to shading, can be compensated by an increase of the light intercepted by the crop, induced by an increase in specific leaf area and, consequently, in total leaf area (Lorenzo et al., 2004).

External mobile shading increases tomato water use efficiency and marketable yield by reducing crop transpiration and incidence of BER, especially when water of moderate salinity is used (Lorenzo et al., 2004).

Whitening is a cheap method to reduce, in warm countries, the heat load during the high radiation season, limiting the solar radiation transmission with positive effects on microclimate, reducing air VPD and temperature. Whitening does not affect the greenhouse ventilation, while internal shading nets do, and whitening increases the fraction of diffuse irradiance, which is known to enhance the radiation use efficiency.

Plant response to evaporative cooling is not always positive, since physiological disorders like BER may be fostered under high radiation and high humidity conditions (Montero, 2006). Evaporative cooling is most efficient in dry climate areas, especially when air humidity falls below 40% RH (Montero, 2006).

Low cost low-pressure misting nozzles can be useful for cooling simple greenhouses or screen houses, but a VPD-basal controller (capable of providing intermittent misting for relative short intervals) should control the system (Montero, 2006).

Comparative studies on the use of the various cooling methods are scarce. In the Mediterranean area, cover whitening was the most profitable cooling treatment as compared with fogging (high pressure) and forced ventilation, when growing soilless pepper during the summer season. Forced ventilation was the least effective cooling strategy, maintaining higher air temperature and higher VPD values (Gazquez et al., 2006). Lowpressure fogging (misting) did not improve pepper commercial yield in comparison with whitening, as the higher precocity in the misted peppers was compensated by lower quality due to BER (Meca et al., 2006).

3. CO_2. Air CO_2 content is an important microclimate parameter in greenhouses for its relevant effect of plant CO_2 assimilation, affecting plant productivity (Kimball, 1986). The increase in photosynthesis and hence assimilate supply contribution, by reducing the intensity of sink competition rather than changing the priority in competition to a yield increase (Ho, 1995), with indirect effects on quality. CO_2 injection is extended in the "Northern greenhouse agrosystem" but scarcely used in low-cost greenhouses.

Cultural Practices and Quality

A high quality product must be safe and healthy, with no chemical residues. The former extended chemical control of pests and diseases for plant protection has been progressively substituted by IPM (integrated pest management). IPM has limited the use of pesticides in the Mediterranean greenhouse industry (Baudoin, 1999). Integrated production and protection (IPP) management programs that deal with pest and disease complexes affecting the crop have been developed (Hanafi, 1999).

An effective IPP management strategy for protected cultivation must also include general plant hygiene measures inside and outside the greenhouse, removing and destroying all crop residues, the use of appropriate cultivars, proper irrigation and fertigation scheduling, and the use of adequately ventilated greenhouses (Papasolomontos, 1997). Complementary measures for the control of pest and diseases should include rotation, soil solarization, grafting on resistant rootstocks, proper ventilation, optimising plant density, use of adequate cladding films (thermal, anti-drip), mechanical barriers (vents-netting) and double doors (Papasolomontos, 1997). Reduction in chemicals is also a result of IPP management; in Europe the extended use of bees (bumble and honey bees) for pollination (instead of the fruit set chemicals used in former years) has limited spraying with broad-spectrum pesticides (Hanafi, 1999; Baudoin, 1999), contributing to improved quality of the produce.

PRODUCTION STRATEGIES FOR SUPPLYING THE MARKETS

Site selection appears as a key aspect of the profitable greenhouse production, especially important for the microclimate conditions, but also for other technical and socioeconomical aspects (water and electricity supply, communications, labour availability, etc.) that influence production costs and competitiveness (Castilla and Hernandez, 2005).

The microclimate conditions, primarily, determine the election of the “greenhouse technological package” (structure, covering and climate control equipment), in order to produce with the required quality at a competitive cost. The distance to the markets can limit the competitiveness of the produce due to the transportation costs, especially in exportfocused production (Castilla et al., 2004).

The challenge to supply high quality vegetables year-round can be afforded in two basic strategies: A) Growing in a high-tech greenhouse year-round, or B) Growing in two, or more, different locations, whose harvesting periods are complementary, enabling a continuous and coordinated year-round supply to the markets.

Alternative A has been chosen by some growers of the “Northern greenhouse agrosystem,” that implement their greenhouses with artificial lighting systems for highquality vegetables produced during the low radiation season. In temperate, subtropical or tropical areas, this alternative A is not economical, in most cases, basically due to the competitive open-air and low-cost greenhouse production from nearby areas, whose harvesting periods sometimes overlap.

Producing in two different locations (alternative B), frequently with different greenhouse agrosystems, is becoming an increasingly adopted strategy. Recently, in Holland, an increasing number of growers semigrate, i.e. they start a farm abroad (e.g. in Spain) and keep also their farm in the Netherlands. The main aim of semigration is to be able to have a continuous production throughout the year (Marcelis et al., 2002).

In the south of Spain, the absence of greenhouse production in coastal areas during the summer months is being substituted by the vegetables produced from the highlands, preferably from net-cladded greenhouses, enabling the year-round market supply. In a similar way, some larger companies in North America are complementing their protected cultivation harvesting calendars, in Southeast Canada and Northeast USA, with produce from Mexico, optimising their integral cost prices on the markets year-round for highquality vegetable commodities.

GREENHOUSE TECHNOLOGICAL PACKAGES

The agronomic performance of greenhouse crops is related to the technological level of the greenhouse, its equipment and management. The lower level is the passive greenhouse, with no climate control equipment, while the fully equipped greenhouse constitutes the higher level, where it is used. In between both extremes, according to the local microclimate conditions and the chosen greenhouse production strategy, different “greenhouse technological packages” are available. Tables 1 to 5 summarize some of those packages in several European and North-African countries.

As greenhouse structure and equipment costs are not standardised, in some cases there are relevant differences between their costs. The various reported greenhouse technological levels (Tables 1 to 4) differ between countries. For example, in Morocco (Table 4) even level 3 is poorly equipped. On the contrary, in the Netherlands (Table 5) the standard greenhouse package is the high-tech Venlo glasshouse.

Growing with level 1 packages, of low cost and no active climate control (Tables 1 to 4), limits good quality production to some months of the year. The investment costs of these packages (level 1) in those Mediterranean countries of mild winter climate (Tables 1 to 4) are around 10% of the investing costs of a standard glasshouse in the Netherlands (Table 5). However, those growers that pretend to rise the quality of their crops and extend their growing calendars must choose a better equipped option, with air heating system (level 2, Tables 1 to 3), in a first step. Further improvements involve higher investments for a fully equipped plastichouse in the Mediterranean area (Tables 1 to 3). Obviously, there are other different and intermediate options of "greenhouse technological packages", in between those reported, according to the growers' priorities.

The production costs are very dependent not just on the fixed costs (related with the greenhouse package), but also on the variable costs, very influenced by the yield performances and the costs of energy, especially due to heating (Castilla et al., 2004).

FINAL REMARKS

The fresh vegetables markets are highly globalised and competitive, as consumers are requiring year-round healthy, safe and high quality products. Growers have to produce in an environmental-friendly, labour safe and hygienic way.

Two basic greenhouse-growing strategies can cover this demand. Growing in two or more different sites, whose harvesting periods are complementary, or producing in high-tech greenhouse during the whole year. The latter option involves a higher "greenhouse package" investment.

Site selection is a key aspect for profitable greenhouse production, specifically for the climate conditions that influence the cost and quality of the produce, but also for the distance to the markets. An economic compromise between the higher investment costs of betterequipped greenhouses and their agricultural performances is needed, in order to produce highquality commodities at competitive levels.

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Table 1. Average investment costs in the south of Spain (in 2006) for three different levels of greenhouse technological packets (structure and equipment). Prices of the land and climate and fertigation computers are not included. Costs calculated for one ha size minimum area. Polyethylene (PE) film cladding is included.

			Euros m^{-2}
LEVEL 1	Low roof slope (parral type) greenhouse	8.5	
	Drip irrigation system	2.2	
	TOTAL		10.7
LEVEL 2	High slope (parral type) greenhouse	11.3	
	Drip irrigation system	2.2	
	Hot air heating system	3.1	
	TOTAL		16.6
LEVEL 3	Arched multispan greenhouse	18.0	
	Drip irrigation system	2.2	
	Heating system (steel tubes)	13.6	
	Fans (air mixing)	1.2	
	Misting system (low pressure)	2.0	
	Shading-thermal screen	5.0	
	TOTAL		42.0

Source: Dr. I. Escobar (personal communication)
Simple soilless system (without drip) costs 1.5 euros m^{-2}.
Greenhouses with motorised side and roof vents (simple system).

Table 2. Average investment costs in Greece (in 2006) for three different levels of greenhouse technological packets (structure and equipment). Prices of the land and climate and fertigation computers are not included. Costs calculated for a 0.5 ha size minimum area. Polyethylene (PE) film cladding is included.

			Euros m^{-2}
LEVEL 1	Wooden structure (side and roof vents)	7.0	
	Drip irrigation system	1.0	
	TOTAL		8.0
LEVEL 2	Tunnel greenhouse (no roof vents)	11.1	
	Drip irrigation system	1.0	
	Hot air heating system	3.0	
	TOTAL		15.1
LEVEL 3	Arched multispan greenhouse (roof vents; double cover – PE)	14.8	
	Drip irrigation system	1.0	
	Thermal screen	3.5	
	Heating system (air+plastic pipes)	10.0	
	Fans (air mixing)	1.2	
	Fan and pad cooling system	5.5	
	TOTAL		36.0

Source: Dr. N. Katsoulas (personal communication)

Soilless system (without drip) costs 1.8 euros m^{-2}. Misting system costs 3.0 euros m^{-2}. Alternatively, glasshouse (structure and glass) for level 3 costs 20.0 euros m^{-2}.

Table 3. Average investment costs in Sicily (Italy, in 2006) for three different levels of greenhouse technological packets (structure and equipment). Prices of the land and climate and fertigation computers are not included. Costs calculated for a 0.5 size minimum area. Polyethylene (PE) film cladding is included. Level 3 is mostly used for high value crops (ornamentals).

			Euros m^{-2}
LEVEL 1	Wooden greenhouse (side vents)		8.0
	Drip irrigation system		2.0
		TOTAL	10.0
LEVEL 2	Arched multispan greenhouse (no roof vents)(*)		13.0
	Drip irrigation system		2.0
	Hot air heating system		3.5
		TOTAL	18.5
LEVEL 3	Arched multispan greenhouse (roof vents)		27.0
	Drip irrigation system		2.0
	Heating system (steel tubes)		20.0
	Fans (air mixing)		2.1
	Misting system (low pressure)		4.1
	Thermal screen		6.9
		TOTAL	62.1

Source: Dr. C. Leonardi (personal communication). Soilless system cost is around 5.8 euros m^{-2}. (*) Depending on the height can vary from 10.0 to 16.0 euros m^{-2}.

Table 4. Average investment costs in Morocco (in 2006) for three different levels of greenhouse technological packets (structure and equipment). Prices of the land and climate and fertigation computers are not included. Costs calculated for a 0.5 ha size minimum area. Polyethylene (PE) film cladding is included.

			Euros m^{-2}	
LEVEL 1	Structure (wooden, Canary type)		3.3	
	Windbreaks		1.5	
	Drip irrigation system		3.5	
		TOTAL		8.3
LEVEL 2	Structure (metallic, Canary type)		4.3	
	Windbreaks		1.5	
	Drip irrigation system		3.5	
		TOTAL		9.3
LEVEL 3	Arched multispan structure (no roof vents)		5.3	
	Windbreaks		1.5	
	Drip irrigation system		3.5	
	Soilless system		7.0	
		TOTAL		17.3

Source: Dr. A. Hanafi (personal communication)

Table 5. Average investment costs in the Netherlands (in 2005) for two glasshouse technological packets (structure and equipment). Price of the land is not included. Costs calculated for one ha size minimum area. Standard Venlo includes structure, wide single glass, energy screen, rain and condensation water collection, water heating system (steel pipes), CO_2 injection, heat storage tank, drain water disinfection and soilless recirculation systems.

			Euros m^{-2}
STANDARD	Standard Venlo type greenhouse and equipment	96.0	
	TOTAL		96.0
HIGH LEVEL	Standard Venlo type greenhouse and equipment	96.0	
	Lighting system (600 W high pressure sodium lamps; one lamp per 12.5 m^2)	22.2	
	TOTAL		118.2

Sources: Van Woerden (2005); E. Van Os (personal communication).