27

Serie Economía

Greenhouse agriculture in Almería

A comprehensive techno-economic analysis

Diego Luis Valera Martínez
Luis Jesús Belmonte Ureña
Francisco Domingo Molina Aiz
Alejandro López Martínez

cajamar
CAJA RURAL

Greenhouse agriculture in Almería

A comprehensive techno-economic analysis

Serie **Economía** [**27**]

Greenhouse agriculture in Almería

A comprehensive techno-economic analysis

Diego Luis Valera Martínez
Luis Jesús Belmonte Ureña
Francisco Domingo Molina Aiz
Alejandro López Martínez

cajamar
CAJA RURAL

bital
UNIVERSIDAD DE ALMERÍA
CENTRO de INVESTIGACIÓN en
BIOTECNOLOGÍA AGROALIMENTARIA

UNIVERSIDAD DE ALMERÍA

ceiA3
campus de excelencia internacional
agroalimentario

Greenhouse agriculture in Almería. A comprehensive techno-economic analysis

Edited by: Cajamar Caja Rural
www.publicacionescajamar.es
publicaciones@cajamar.com

Design and layout: Beatriz Martínez Belmonte
ISBN-13: 978-84-95531-75-9
Legal Deposit: AL-256-2013
Release Date: marzo 2016

Foreword

One of the key objectives laid out by the Cajamar Chair of Economics and Agri-food of the University of Almería since its foundation in 2009 was to provide the agri-food sector with research findings and field work that could help us understand better the «high-yield horticultural production system of Almería», serve as valuable tools in the process of decision making in the technical, social and economic domains, and promote the benefits of this model on a global scale.

With this motive in mind, the Chair presents this work, which focuses on achieving the following goals:

1. *Characterise the high-yield horticultural production system of the province of Almería.*
2. *Evaluate the different technological levels of the system.*
3. *Obtain profitability data from different types of agricultural holdings within the system.*
4. *Classify the different technological levels based on profitability.*

Throughout the various chapters of this book, this study analyses the greenhouse horticulture of Almería, starting with a brief historical overview, assessment of the current state, and description of the primary crops and different technological elements of the productive structures. Subsequently, the process of data collection is described and the results of the technological evolution and its economic impact are shown. Finally, the profile of the most profitable fruit-and-vegetable holding system for each region and crop type is described. The book concludes by summarising the main conclusions of this work.

I would like to highlight a key phrase that the authors included in the main text: «The combination of Almería-type greenhouses with sanded plots is still, after 50 years, in excellent condition as a result of its profitability and energy efficiency».

The Cajamar Chair of Economics and Agri-food of the University of Almería appreciates the efforts made by the authors of this study and, above all, appreciates their approach to publication because it helped improve our understanding of many of the details of the production system in our region. The two institutions that support the Chair expect that this text will be useful to the most important economic sector of the province and hope that it will be an effective tool for the development of further improvements.

Francisco Camacho Ferre
Director of the Cajamar Chair of Economics and Agri-Food
of the Universidad of Almería

Acknowledgements

First, we would like to acknowledge the invaluable assistance that we received from the 212 farmers who participated in this project and the 18 most important companies that produce and market fruits and vegetables in the province. Without their selfless assistance, this manual would not have been produced and would not reflect the current state of early-season crops in the greenhouses of Almeria.

We would also like to extend our gratitude to the members of the Advisory Council of the Cajamar Chair of Economy and Agri-food of the University of Almería, particularly to its Director, Mr. Francisco Camacho Ferre, for providing encouragement and for the patience, dedication and knowledge extended to us in our moments of doubt.

Professor Francisco Camacho has once more shown his generosity and altruism in sharing his profound knowledge of the Agricultural Model of Almeria, and we have had the great fortune of his assistance from the beginning of this work. His wise guidance, support, advice, and invaluable review of the manuscript greatly contributed to this work.

We would also like to thank the University of Almería, the Research Centre for Agri-Food Biotechnology of the University of Almería (BITAL), and the Agri-Food Campus of International Excellence (ceiA3) for their invaluable support in developing the English version of this work.

Finally, we appreciate the work of our research team, especially the colleagues who accompanied us in the development of the field work: Patricia Marín, María Ángeles Moreno and María del Carmen Márquez; and in the English review: Carlos Herrero Sánchez. We would also like to thank our respective departments of the University of Almería. In addition, we are especially indebted to Patricia Marín Membrive, agricultural engineer and current PhD candidate, who provided us with intensive and invaluable assistance in developing this research work.

The authors

1. Introduction and objetives

It has been well documented that the greenhouses in Almería, Spain, have driven the demographic and socio-economic development in the province for decades. Season after season, their production (3.2 M€) and value (1,700 M€) have been the central core of the province's economy. In addition, the 30,000 ha of greenhouses provide significant export value (70 %) and have contributed the largest share of the international agri-food trade within Andalusia.

However, the loss of income for farmers continues because the actual prices (discounting inflation) have followed a downward structural trend over time. Therefore, it would be of great value for the sector to determine the level of technology at which profitability for each crop is maximised. Therefore, at the core of this new approach is the crop and technology is consequently adapted to it. In this context, it is obvious that planning crops according to market trends plays a key role from the start of the production process.

Thus, under the guidance of professors Eduardo Fernández Rodríguez†, Luis Fernández-Revuelta and Francisco Camacho Ferre of the University of Almería, an initial approach was developed based on the previously mentioned philosophy and was applied in 2004 to a company in Campo de Níjar (Almería, Spain). Among the interesting findings of this study was that in general terms performing crop management under increasingly technologically advanced structures does not necessarily result in direct increases of commercial productivity and economic performance. This result confirmed the interest of specialising in those crops that effectively render the investments profitable, such as that of long-cycle tomato, which confirmed a higher economic performance.

This is the backdrop to the present work, for which the sample universe has now been expanded to include the four agricultural regions of Almería Province, Spain: Campo de Dalías, Bajo Andarax, Campo de Níjar and Bajo Almanzora (Figure 1). In addition, 212 farmers and 18 companies that produce and market agricultural products were interviewed, and 685 ha of greenhouses were sampled, equalling 2.4 % of the province's total extension.

In addition, the Research Project directed in 1997 by Diego Luis Valera Martínez and Jesús Antonio Gil Ribes, which was funded by the Almería Provincial Council, provided useful technological characterisations of the agricultural holdings (Molina-Aiz, 1997). In this study, in situ surveys were conducted with farmers from 526 greenhouses across the province (69.8 %

in Campo de Dalías, 7.4 % in Bajo Andarax, 20.8 % in Campo de Níjar, and 1.9 % in Bajo Almanzora). The real surface sampled was 340 ha, which represented a sampling rate of 1.4 % of the total greenhouse surface of the province. This preliminary work has served as a source of data, some of which were published by Valera *et al.* (1999b), with other data unpublished, for the analysis of the development of greenhouses in Almería over the past 16 years (from 1997 to 2013).

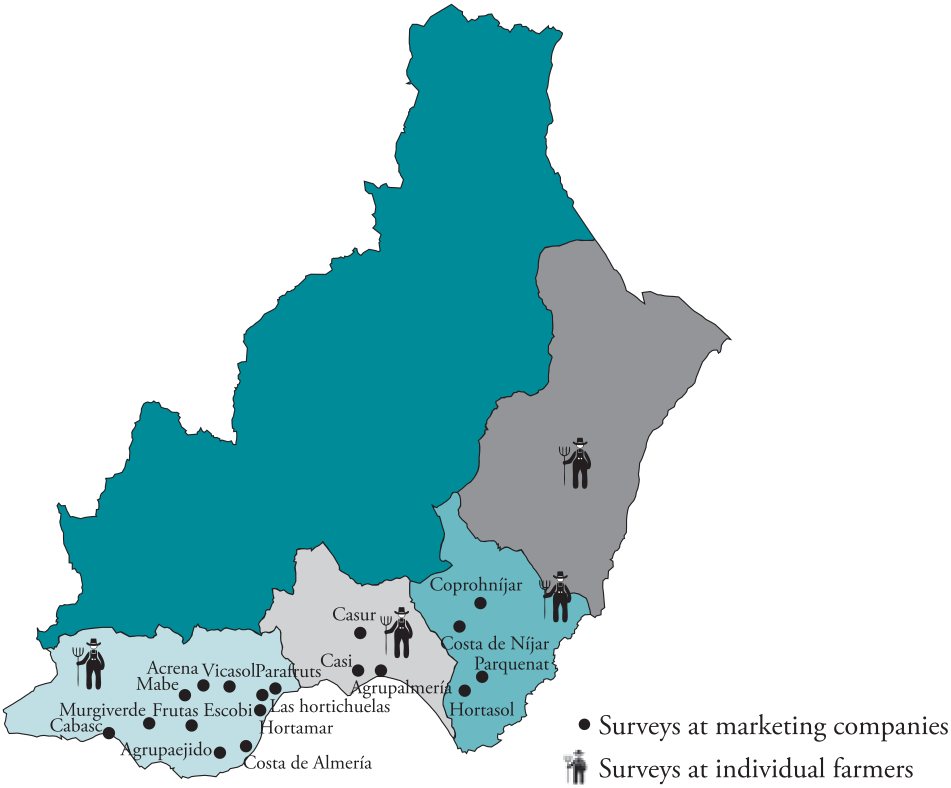
Figure 1. Four main agricultural regions of Almería

In the current study, the extraction of data, both qualitative and quantitative, was performed at two levels: through a survey of 108 questions conducted with each of the 212 participating farmers and through data provided in a spreadsheet completed by the 18 participating companies that market agricultural products.

The vast majority of farmers belonged to these 18 companies, which allowed for a comparison of the information provided. Normally, companies would bring us into contact with 10 of their farmers, and the surveys were performed at the company headquarters. However, a control group of 48 individual farmers that did not belong to the 18 participating companies was established to extend the sampling validity.

Figure 2 shows the location of the collaborating companies and those areas where the individual farmers (control group) were interviewed.

Figure 2. Location of the collaborating companies



Qualified personnel conducted the surveys for each farmer. Due to the wide scope of the survey, each interview required 45 minutes and consisted of the following sections:

a) *Personal data and socioeconomic aspects.* Age of the farmer, geographical origin of the producer, number of years dedicated to agriculture, educational level of the farmer, occupation in addition to farming, professional background of the holder, size of the agricultural holding, number of greenhouses in the holding, required labour and origin, and greenhouse area in each holding compared with the total area of the holding.

b) *Crops*. Weed elimination method, seed planting type and method, seedling (root-ball type) transplantation, foliar analysis, crops in the latest seasons, plantings and their yield, alternative phytosanitary application systems, pollination methods, graft usage, etc.

c) *Machinery*. Type of machinery used for the application of phytosanitary treatments, vehicles used in holdings, frequency and type of work conducted to prepare the land, hiring of machinery or operators for such work, etc.

d) *Soil*. Soil analysis, soil disinfection type and frequency, greenhouse surface soil type, manure broadcasting, broadcasting frequency, greenhouse surface area, product type, approximate cost, quantity provided and approximate cost, humic acid contribution, when relevant.

e) *Auxiliary buildings and irrigation systems.* Surface of storage areas and irrigation huts; number of irrigation ponds and their volume; type of material used in pond manufacture; shape of the pond; type of irrigation head, filter, fertigation system, etc.; type of water collection; type of dripper and density; analysis of water source and cost; electrical conductivity of water; equipment for measurements, such as tensiometers, etc.; installation of an irrigation programmer (type); number of existing tanks; and engine power of the irrigation system.

f) *Marketing*. Association of each agricultural holding to the company that markets its products; data obtained from years of partnership; type of expertise; preparation of product before delivery to the store; system of certification; and data on income, expenses, and yields.

g) *Structure*: Number of greenhouses, type and material of structures; surface, orientation and auxiliary elements used in production, including double roofs, double doors, lined corners, shade screens, insect-proof screens, etc.; height of the greenhouse; changes made to the greenhouse throughout its life; age and cost of greenhouse construction; surface of side and roof openings; corridor surface area; type and duration of plastic used; and cost of labour to replace plastic, perform whitewashing, whitewash cleaning, etc.

h) *Climate control systems*: Availability of climate controller, display type, forced ventilation system, water evaporation cooling systems and heating systems; fuel used; energy-saving techniques; and other advanced climate control systems.

i) *Cost-benefit analysis.* Earnings, expenses, most profitable crops, crops that require high initial investments, subsidies, credits, etc.

j) *Labour.* Type, work contracted for, quantity, etc.

The information obtained from the farmers who participated in the surveys has been complemented with farm income data over six agricultural seasons (from 2006/07 to 2011/12). Farm income data have been provided by the companies that market agricultural products, which have also contributed additional parameters (per farmer), such as the product and variety, marketed volume, property surface, greenhouse type, and other qualitative parameters of special interest for the study.

To determine the municipalities that compose each agricultural region, we have complied with the provisions established by the Ministry of Agriculture, Fisheries and Environment of the Regional Government of Andalusia (CAPMA, 2013a). The following figures show the municipalities that compose the four study areas.

The general objectives of this study can be summarised as follows:

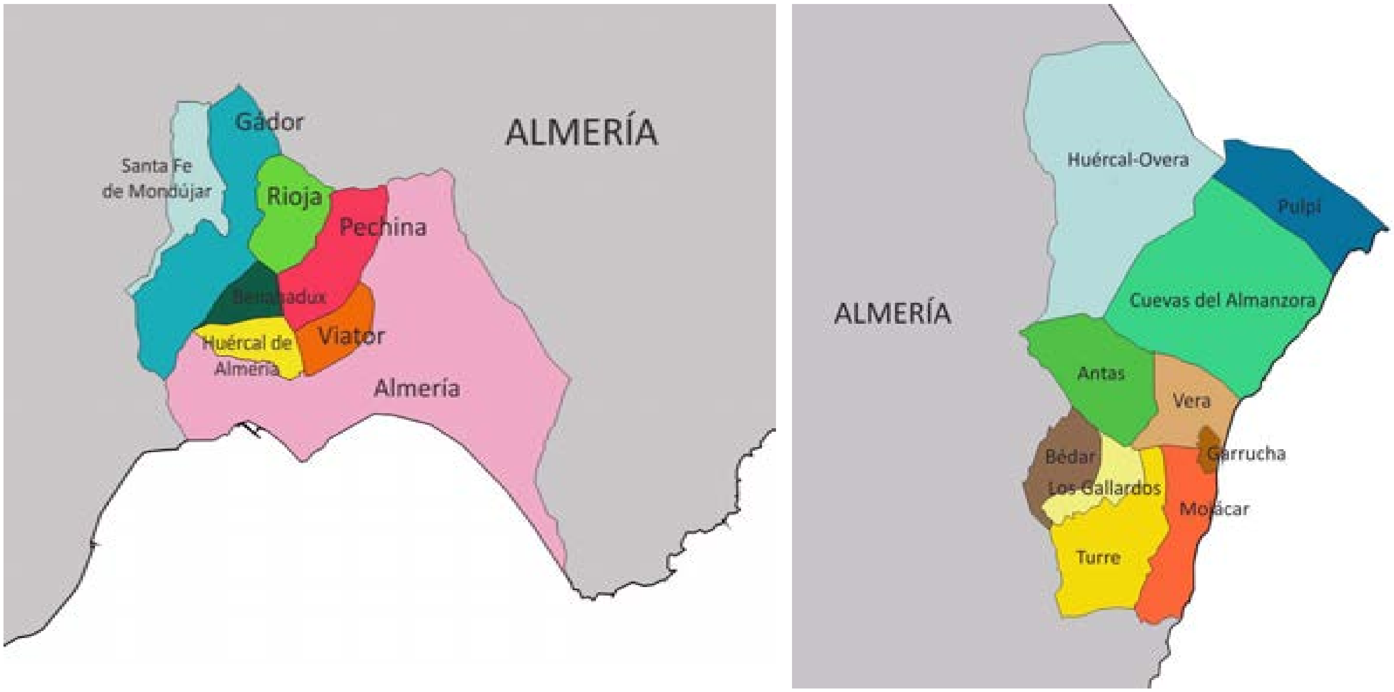
1. Characterise greenhouse production systems in Almería.
2. Evaluate different technological levels of the Almería Agricultural Model.
3. Extract economic profitability data of the agricultural holdings.
4. Determine the average profile of the agricultural holding with the highest estimated average earnings by season.
5. Establish the average profile of the agricultural holding with the highest production yields per season depending on the combination of crops and cycles used.

Figure 3. Municipalities by region

Campo de Dalías

Campo de Níjar

Figure 3 (cont.). Municipalities by region



Bajo Andarax

Bajo Almanzora

Source: Consejería de Agricultura, Pesca y Medio Ambiente de la Junta de Andalucía (CAPMA, 2013b).

2. Intensive horticulture in the greenhouses of Almería

2.1. Brief historical review

The first references to the advantages gained from incorporating a layer of sand into the ground are found in the Treaty of Agriculture written by Ibn Luyun, from Almería, in approximately 1348 (Eguaras, 2014). However, the origin of the sand-plot technique in modern horticulture dates to 1880 along the coast of Granada in La Rábita and El Pozuelo in the municipality of Albuñol, which borders the province of Almería. Such method spread to the areas of Adra and Guardias Viejas, although the definitive impetus came later at the hands of the National Institute of Colonisation (NIC). Several reports from the institute written by the agricultural engineers Leandro Pérez de los Cobos and Bernabé Aguilar Luque reflect the advantages of the sanding technique in alleviating high salinity in water while also improving production and reducing growth cycles.

Around the year 1940, farmers from La Rábita terraced and sanded a farm near the beach in the La Romanilla area in Roquetas de Mar.

According to Rivera (2010), the use of sand plots did not increase until the plots managed by the NIC demonstrated their profitability; the same trend occurred for the use of greenhouses, whose implementation occurred through subsidies and aid from the NIC, subsequently renamed the Institute of Reform and Agricultural Development (IRYDA). The first 20 ha of plots were delivered to settlers in the summer of 1956 and sanded that same year. Settlers continued arriving from that date until the beginning of the 1980s.

In 1956, according to reports by the NIC agricultural engineer Bernabé Aguilar Luque, NIC technicians created two pilot holding units: one without sand and one with sand. Plot 24 (3.13 ha) in the irrigation sector of Aguadulce was without sand, and the settler charged with the plot under the guidance of the NIC beginning in August of that year was Francisco Sources Sánchez, better known in the area as «Paco el piloto». Successive trials over several years on this plot without sand were not particularly successful. Plot 74 was the sand plot (3.4 ha), and the selected settler was Francisco López Fernández, a farmer from Adra, where the sand-plot system had already been exploited for four years. Trials with this technique were satisfactory, and the practice expanded rapidly through the area. NIC technicians demonstrated their innovative mindset, and the boom in intensive agriculture practices in Spain is owed to them.

In 1960 in plot 24 (where earlier tests were performed on soil without sanding), the first plastic coating was installed. The first step consisted of applying mulching with transparent polyethylene (PE) sheets and surrounding the plants with PE with a small wire frame and small tunnels. This installation had limited success.

However, significant advancements were made in 1963 with the installation of a protective polyethylene film onto a simple and lightweight structure similar to what was used to guide the vines of table grapes (Aguilar, 1981). The developers of this concept (the Almería-type greenhouse) were the agricultural engineers Leandro Pérez de los Cobos and Bernabé Aguilar. In plot 24 on a surface of 500 m^2, a parral, or vine arbour, type of structure based of eucalyptus timber was installed, with a 100 m^2 sanded area remaining as a control in the open air protected by windproof hedgerows. NIC operators working in the vineyards of Campo de Níjar (Rivera, 2000) were consulted. The success of the sanding and greenhouse structure combination was immediate, and the following year, four new greenhouses were built to serve as information source.

The results of combining sanding and greenhouse structures were satisfactory and served as the source of the dramatic socio-economic and demographic development that Almería has experienced in the last decades.

The drivers of the expansion of sand plots and greenhouse agriculture were the agricultural engineers Bernabé Aguilar Luque and Leandro Pérez de los Cobos from the Almería Office of the National Institute of Colonisation and the agricultural engineer Manuel Mendizábal Villalba from the Agronomic Head Office of Almería.

2.2. Current situation of intensive horticulture in Almería

Almería greenhouses have driven the demographic and socio-economic development in the province of Almería for decades, and we have recently celebrated the 50th anniversary of the construction of the first greenhouse in the area. Almería greenhouses constitute the largest concentration of greenhouses in the world, and season after season, their production and value represent the central core of the provincial economy.

According to the Andalusian Agency for Foreign Advancement (EXTENDA), Andalusia was the leader in agri-food exports in Spain for the first half of 2013, and this was due in large part to Almería's horticulture, which contributes the largest share to the international Andalusian agri-food trade.

Currently, a clear segmentation can be observed in the companies that produce and market agricultural products between a small group of companies that have a significant volume of turnover and a large group of smaller companies. However, merger and absorption processes have occurred in recent years, and the top ten groups of agricultural marketers represent 75 % of all turnover of this sector in Almería (Aznar *et al.*, 2013). However, distribution chains in the target markets are highly concentrated and have a dominating negotiating position, thus imposing lower prices and increasing the required protocols in the producing regions.

The agricultural economic returns in Almería are much higher than in the rest of Spain, and the average holding size is small, which historically has imbued the region with a strong social character and has led to the distribution of wealth. Currently, the greenhouse surface per agricultural holding is being increased in an attempt to preserve farmer incomes.

In addition, greenhouse production is notable for its high water and nutrient-use efficiency. The favourable climate, furthermore, allows for much lower energy consumption than is found in other growing areas, such as in Dutch greenhouses. For example, greenhouse production in Almería requires 22 times less energy than in the Netherlands.

In recent years, a sustained investment effort has been made to improve food safety. Almería has the highest density of accredited laboratories, and waste management has improved substantially because of rural hygiene plans and agricultural best-practices protocols.

Environmentally, the greenhouses have positive effects that are not always well acknowledged, including the temperature drop in the area caused by the reflection of solar rays on the roofs of greenhouses, which increases the albedo over thousands of concentrated hectares of greenhouses in Almería. According to Campra *et al.* (2008), the recent development of intensive horticulture in the area compensates the local warming associated with increases in global greenhouse gases.

Thus, it is worth highlighting the effect of greenhouses as CO_2 sinks because of the enormous plant density and their large production areas. Greenhouses are similar to a forest that is not visible because it is covered with plastic. They greatly decrease the concentration of CO_2 in the area, which is one of the major greenhouse gases that cause global warming. In the 2012/13 season, pepper and tomato greenhouse crops in Almería fixed an impressive amount of 515,672 tonnes of CO_2.

However, most notable in recent years is the «Green Revolution» in the field of biological control based on the use of natural enemies to control organisms deemed harmful to plants. This natural method of eliminating pests using beneficial insects improves the productivity of the crop and protects the environment by drastically decreasing the use of phytosanitary products and working to achieve «zero residue». This practice began in 2005, and the results until now have been excellent.

According to the Territorial Office of the Ministry of Agriculture, Fish and Environment (CAPMA) of the Regional Government of Andalusia, 26,720 ha were treated with biological control techniques in the 2013/14 season. This represents 93 % of the surface and 65 % of the production of Almería, thus ranking Almería as a world leader in total volume grown with biological control techniques and resulting in a large competitive advantage over other production regions.

In the current environment of general crisis, agriculture has been the only solid economic foundation for Almería. Owners and families have again become more intensely focused on agricultural holdings, and since the 2011/12 season, the greenhouse surfaces have increased, which had not occurred since 2006 (CAJAMAR Foundation, 2012).

In the agricultural season (2012/13), the production of greenhouse crops in Almería accounted for 2.6 million tons, which had a value of € 1,528 million. The 3 % decrease of market volume has been compensated for by a 17 % average price increase and 13 % increase of total revenues (COEXPHAL, 2013). Most of the intensive horticulture of Almería is destined for export markets, and sales in foreign markets are close to 70 % (Aznar *et al.*, 2013), with the main markets being Germany, France, the Netherlands and the United Kingdom.

However, a small deviation from the information provided by the Territorial Office of the Ministry of Agriculture, Fish and Environment (CAPMA) of the Regional Government of Andalusia was observed in relation to vegetables. According to CAPMA (2013b), the total physical greenhouse surface in Almería during the 2012/13 season increased to 28,576 ha, and the grown surface (considering cycles) of vegetables (non-fruit and vegetables) increased by 11 % over the 2011/12 period, resulting in two consecutive grow seasons. The 2012/13 season set a new production record and exceeded the results of the preceding period by 2 %. Courgette, peppers, tomatoes, and green beans further increased their production compared with the average for the 2009/12 period (CAPMA, 2013a).

A detailed analysis of the main parameters for crops was performed for the last fully analysed season, which was 2011/12 (Table 1). Tomato exports increased in volume and economic value by 14 % compared with the average of the three previous seasons. Pepper exports increased by 13 % compared with the 2010/11 season. Cucumber exports increased 25 % compared with the three previous seasons, and courgette increased by 17 % compared with the previous season. However, the volume of exported melon dropped by 16 % compared with the 2010/11 season, whereas watermelon exports slightly increased (2 %). Finally, the average price of eggplant greatly increased (61 %) and bean exports increased 16 % compared with the 2010/11 season (CAPMA, 2013a).

Table 1. Relevant parameters of the principal crops of the 2011/12 season

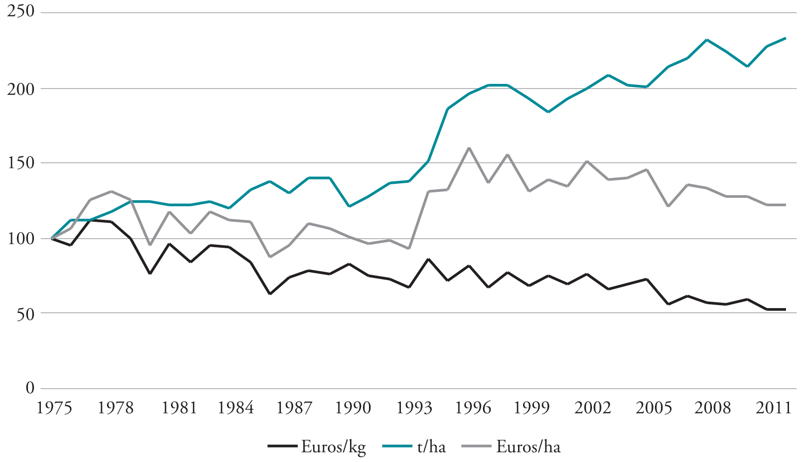
Crop	Surface (ha)	Production (thousands t)	Yield (kg/m²)	Average price (€/kg)	Prod. value (millions €)	Exportation (%)
Tomato	7.850	750	9,56	0,56	420	64
Pepper	7.388	513	6,94	0,63	323	69
Cucumber	4.500	407	9,05	0,42	171	87
Courgette	5.100	348	6,82	0,44	153	64
Watermelon	5.665	350	6,18	0,28	98	41
Melon	3.740	135	3,61	0,40	54	44
Eggplant	1.890	187	9,92	0,38	71	59
Green Bean	1.170	21	1,80	1,41	30	36

Source: Observatory of Prices and Markets (CAPMA). Own elaboration.

During the 2011/12 season, the main types of tomatoes grown in the greenhouses of Almería were long life (38 %), cluster (28 %), pear (15 %), cherry (8 %), smooth (6 %), grooved (4 %), and others (1 %). The main types of pepper were California (63 %), Lamuyo (17 %), Italian (9 %), and others (11 %). The main types of cucumber were Almería (88 %), Short (7 %), and French (5 %). The main type of marketed courgette was green (98 %). Finally, the main types of watermelon were the Rayada (35 %), seedless black (27 %) and seeded black (23 %). With respect to melon, the Piel de Sapo, or Santa Claus or toad-skin melon, (40 %), Galia (28 %), cantaloupe (17 %) and yellow (12 %) stand out. In addition, the best-selling eggplant was the semi-long type (92 %), followed distantly by Rayada (3 %) and Redonda (2 %). A similar trend occurred with green beans, with the flat green bean accounting for 86 % of the total sales, followed by the round green bean (11 %) and other types (3 %) (CAPMA, 2012).

Despite these yield and high export values, the revenue loss for farmers continues (Figure 4). The average per-hectare income has fallen over the long run, which is primarily because of the drop in prices, discounting inflation (CAJAMAR Foundation, 2012). In addition, there has been growing competition from the North, based on the employment of technology, and from the South, based on lowering producing costs and especially the cost of labour, which constitutes the greatest cost.

Figure 4. Average yields and profitability of horticultural production. Index 1975=100



Source: Fundación Cajamar. Estimate based on data provided by CAP, SOIVRE, DGA and data provided by companies in the sector.

Thus, based on this situation, it becomes essential to intensively work upon the following aspects:

- *Marketing*. The goal in this area is to obtain the best prices for farmers. Distribution costs should be reduced by shortening the supply chain, improving agreements with distribution chains, establishing distribution platforms in the target markets, and promoting intermodal transport to avoid eco-taxes for the transport of goods by road in certain countries, such as France and Germany.
- *Costs*. Reduce (or at least co ntrol) production costs.
- *Productivity*. Increase productivity by improving holdings and incorporating technology with the greenhouses when needed.
- *Holdings*. Increase the size of holdings to avoid revenue loss of farmers.
- *Specialisation*. Adjust each crop to the corresponding technological level.
- *Competitive advantage*. Differentiate Almería with respect to our competitors by continuing current efforts in biological control, zero residue, food safety, etc.
- *Waste management*. Solve all waste problems resulting from intensive agriculture (vegetable waste, plastics, etc.) and improve the foreign image of our holdings.
- *Flavour*. Make an effort in plant breeding in order to generalise flavourful varieties without losing the properties of the current varieties, and promote awareness among consumers of the excellent health benefits of bioactive substances that fruits and vegetables contain.

2.3. Crops

According to the results obtained in the survey of surfaces and crop yields (ESYRCE) for 2012, which was published by the Ministry of Agriculture, Food and Environment (MAGRAMA), there is a total greenhouse surface of 42,823 ha in the Andalusian Region. Of this total surface, 68.1 % (29,152 ha) are found in the province of Almería, thus representing 47.9 % of the surface destined for greenhouses in Spain (60,842 ha). This data is slightly lower than that specified in the analysis of the fruit and vegetable season in Almería for the 2011/2012 season published by the Cajamar Foundation, which indicates that 29,991 ha of the surface were destined for greenhouses in the province of

Almería. Based on the different crop cycles, it is estimated that there is a total surface of 46,140 ha grown in greenhouses. However, the CAPMA of the Regional Government of Andalusia established a slightly lower figure of physical surface of greenhouses in Almería in the 2012/13 season of 28,576 ha (CAPMA, 2013b).

We consulted the major seed companies and estimated the crop surface grown under greenhouses (not physical greenhouse surface) in the province of Almería for the 2012/2013 season. The results are as follows: tomato (8,716 ha), pepper (7,588 ha), courgette (5,120 ha), watermelon (2,500 ha), cucumber (4,180 ha), melon (3,220 ha), eggplant (1,900 ha) and green bean (1,200 ha).

According to the Cajamar Foundation Seasonal Report, produce sales during the 2011/2012 season netted € 1.413 billion, which is 6.1 % more than in the preceding year. The most economically important crops were tomato (€ 377 million) and pepper (€ 353 million), followed by cucumber (€ 169 million) and courgette (€ 151 million). Another economically important fact is that during the 2011/2012 season, exports reached a value of € 1.741 billion, with 69.5 % of the production exported. Exportations increased 9.2 % with respect to the 2010/2011 season. In terms of the costs associated with intensive horticultural holdings, the most important item corresponds to labour (40 % of annual cost), followed by seeds and propagating material (8.4 %), fertilisers (7 %), pesticides (5.9 %), chemical control (4.1 %) and biological control (1.7 %). The depreciation of facilities amounts to an average of 23.7 % of annual expenditures (Cajamar Foundation, 2012).

In the following sections, a brief description is provided of the main characteristics of the eight most important species grown in the greenhouses of Almería.

2.3.1. Tomato

The province of Almería has 10,232 ha of greenhouses in which tomato is grown, with a production of 958,462 tonnes (CAPMA, 2013a), which represent 83.2 % of the surface and 61 % of the total production in Andalusia (Junta de Andalucía, 2010). Tomato (together with pepper) is one of the main crops of the province, with an economic impact during the 2011/2012 season of € 377 million (Cajamar Foundation, 2012).

Tomato (*Solanum lycopersicum*) belongs to the Solanaceae family. Although of Andean origin, domestication appears to have occurred in Mexico (Camacho, 2003). Tomato is a multiannual herbaceous plant that is grown as an annual (short cycles of 4-5 months or long cycles of 8-9 months), and it has a creeping stem capable of rooting, although it is normally grown on trellises. The planting framework tends to maintain a distance of 80-100 cm between rows and 30-50 cm between plants (Marín, 2013), and the framework used in the province of Almería may vary depending on the variety, crop cycle, greenhouse type and soil or substrate type (Camacho, 2003). Crop cycles can be differentiated as follows. (i) Short autumn cycles, in which transplantation is performed in late August or early September and harvest usually occurs from November to January or February. (ii) Short spring cycles, in which transplantation occurs in January or February and harvest tends to occur from May to July. (iii) Long autumn-winter-spring cycles, in which transplantation is performed in late August early September and harvest usually occurs in mid-December and continues until July (Camacho, 2003). The different varieties of tomatoes for fresh consumption can be classified according to their shape (Marín, 2013):

- *Indeterminate growth*: Varieties with stems of continuous growth. The plant is topped to stop its growth after reaching the desired height. (i) Large-calibre tomato (G and GG, average fruit weight ≥ 180 g), with up to 182 varieties and 17 sub-varieties (e.g., Amaral, Abigail F_1, Galo, etc.). (ii) Corazón de Buey, or Oxheart, tomato, with up to 11 varieties (e.g., Corazón F_1, Borsalina F_1, etc.). (iii) Medium-calibre tomato (M and G, average fruit weight between 100 and 180 g), with up to 67 varieties and 11 sub-varieties (e.g., Gabriela, Martina F_1, etc.). (iv) Marmande or grooved-type tomato, with 18 varieties and 1 sub-variety (e.g., Marmande RAF, etc.). (v) Small-calibre tomato (fruit < 100 g), with 10 varieties that mainly include varieties of Canarian tomatoes. (vi) Hanging tomatoes, roma or oval-type tomatoes, San Marzano type, mini San Marzano type, cereza, cherry, miniroma and minicherry types, with up to 193 varieties and 23 sub-varieties. (vii) Cluster-type varieties: medium cluster, with up to 45 varieties and 9 sub-varieties (e.g., Pirate F_1, Palladium F_1, etc.), Cluster-type roma, with 10 varieties (e.g., Cencara F_1, Royalty, etc.), and minicluster, with up to 56 varieties (e.g., Imola F_1, Messina RZ F_1, etc.).

- *Semideterminate growth*: This includes indeterminate varieties. However, because of their growing conditions, they do not grow particularly high. These varieties are medium or thick calibre (e.g., America-3, etc.).
- *Determinate growth*: This includes varieties for which the apical bud transforms into a cluster that stops the growth of the plant, which can be further distinguished as follows: the trellised tomato crops, with four varieties (e.g., Ace, Dalmonte F_1, etc.), and creeping tomato crops, with up to 44 varieties (e.g., Acclaim F_1, Excalibur F_1, etc.).

The marketed tomato types can also be classified as follows (CAPMA, 2012):

- *Long life*. Round smooth fruit of a deep red colour with a long shelf life.
- *Cluster*. Medium-calibre fruit harvested as a cluster; fruit has good flavour, colour and high firmness.
- *Cherry*. Dark or bright red fruit of small calibre.
- *Grooved*. Fruit with flattened shape and highly marked shoulders of dark green that stands out for its excellent flavour and short shelf life.
- *Smooth or salad*. Slightly globose fruit with dark shoulder that is harvested before turning red.
- *Roma*. Fruit with elongated shape of medium calibre and deep red colour.

Figure 5. Types of marketed tomatoes

Long life Grooved Cluster

Smooth or salad *cherry* Roma

Source: CAPMA (2012).

2.3.2. Pepper

Pepper is the second most important crop and close to that of tomato in the economy of the province of Almería, with 8,406 ha of greenhouses and a production of 540,590 tonnes (CAPMA, 2013a), which account for 92.8 % of the surface area and 87.9 % of the total production in Andalusia (Junta de Andalucía, 2010). Pepper crops had an estimated economic impact of € 353 million in the 2011/2012 season (Cajamar Foundation, 2012).

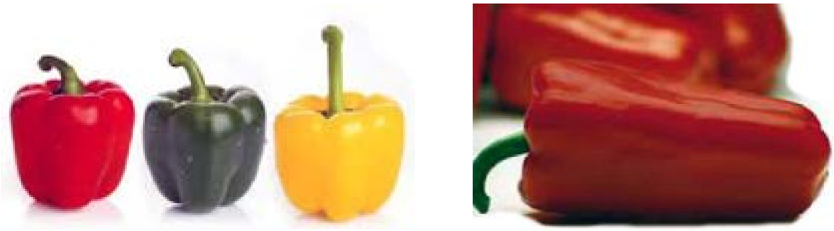
Pepper (*Capsicum annuum* L.) belongs to the Solanaceae family and is an herbaceous annual. Its crop cycle usually is 6-9 months, and the planting framework tends to maintain distances of 80-100 cm between rows and 40-50 cm between plants (Marín, 2013). The most common planting framework are 1 × 0.5, 1 × 0.3 m^2 (individual rows) and 2 × 0.5, 2 × 0.3, 1.5 × 0.5 and 2 × 0.5 m^2 (double rows) (Camacho, 2003). Transplantation date depends on the selected variety, and crop cycles can be differentiated as follows. (i) Extra-early cycle, with transplantation at the end of May or beginning of June. (ii) Early cycle, with transplantation in July or mid-August. (iii) Semi-late cycle, with transplantation at the end of August or mid-September. (iv) Very late cycle, with transplantation at the end of December or late January. The different varieties of pepper for fresh consumption can be classified according to the shape and colour of ripe fruit (Marín, 2013):

- *Rectangular-type or Lamuyo*: Fruits with a rectangular profile, ranging to a truncated cone depending on the variety. From 15-20 cm long and 7-12 cm in diameter. The varieties are classified according to the colour of the ripe fruit, which is red or yellow. In the market, there are 88 varieties (1 sub-variety) with red maturity (e.g., Alcazaba F_1, Daimos F_1, etc.) and 11 yellow varieties (e.g., Tenor F_1, Plinio RZ F_1, etc.).
- *Square-type or California*: Fruits with a square or slightly truncated cone profile depending on the variety. From 8-12 cm long and 8-14 cm in diameter. The varieties are classified according to the colour of the ripe fruit, which is red, yellow, orange, purple or white. In the market, there are up to 117 varieties (16 sub-varieties) with red ripening (e.g., Balboa, Coimbra, Mustang F_1, etc.), 62 varieties (4 sub-varieties) with yellow ripening (e.g., Giacomo, Goldix F_1, etc.) and 9 varieties (3 sub-varieties) with orange ripening (e.g., Caspio F_1, Quirón F_1, etc.).
- *Conical/long-type*: Fruit with a long shape and triangular profile. There are 10 subtypes, which can be classified as follows. (i) Red peppers with 15 varieties (e.g., Adriático F_1, Peleus, etc.). (ii) Yellow pepper, with two varieties (yellow bull horn and Goleen horn F_1). (iii) Sweet Italian pepper, with 52 varieties and 3 sub-varieties (e.g., Abdera F_1, Zanetti, Sweet Italian, etc.). (iv) Hungarian pepper, with 2 varieties (Agio F_1 and Avana F_1); (v) Kaypa pepper, with 4 varieties (e.g., Martinet F_1, etc.). (vi) Mallorcan pepper, with 4 varieties (e.g., Amarillo de Mallorca-Ros, etc.). (vii) Mediterranean pepper, with 1 variety (Plantet F_1). (viii) Padrón pepper, with 8 varieties and 1 sub-variety (e.g., Celta F_1, Padrón Teira, etc.). (xix) Mini pepper, with 4 varieties (e.g., Petit Marseillais, etc.). (xx) Hot pepper, with 36 varieties (Furila F_1, Troner Hot F_1, etc.).

The marketed pepper types can also be classified as follows (CAPMA, 2012):

- *California pepper*. Fruit with square or slightly truncated cone profile that changes when ripening from green to the colour typical of the variety.
- *Lamuyo pepper*. Fruit with a rectangular profile that is generally pronounced, ranging to truncated cone, with a colour that turns red or yellow when ripening.
- *Italian pepper*. Fruit with a conical profile that is generally deformed with a sweet flavour and red ripening.
- *Other merketed types*. Less marketed peppers, such as the Padrón pepper, hot pepper, and other sweet peppers, etc.

Figure 6. Marketed pepper types



California

Lamuyo

Italian

Others

Source: CAPMA (2012).

2.3.3. Courgette

Courgette is a crop of minor importance compared with tomato and pepper. In the province of Almería, courgette is grown in 6,358 ha of greenhouses, which have a production of 371,294 tonnes (CAPMA, 2013a) and account for 94.3 % of the surface and 88.9 % of total production in Andalusia (Junta de Andalucía, 2010). During the 2011/2012 season, the economic impact was estimated at € 151 million (Cajamar Foundation, 2012).

Courgette (*Cucurbita pepo* L.) belongs to the Cucurbitaceae family and is an annual plant with compact growth, a pentagonal stem section (Marín, 2013), and indeterminate and creeping growth types (Camacho, 2003). The crop cycle tends to be 4-6 months, and the planting framework tends to have distances of 100-200 cm between rows and 60-150 cm between plants (Marín, 2013). The most common planting frameworks are 2 × 0,75; 1 × 1; 1,33 × 1; 1,5 × 0,75 m^2, and they are sometimes staggered. Crop cycles can be differentiated between (i) autumn-winter cycles, with transplantation from August to October, and (ii) spring cycles, with transplantation from December until February (Camacho, 2003). The fruit is a pepo, elongated, cylindrical and slightly claviform and either green, yellow or white in colour. There are 149 varieties and 16 sub-varieties, and the majority are green with different tonalities (Marín, 2013). The varieties can be classified based on their growing cycle (Camacho, 2003):

- *Autumn cycle*. Extra early crops with planting dates between the 1st and 15th of August (Cora F_1, Tosca F_1, etc.); early crop with planting dates between the 5th and 10th of September (Consul, Chapin F_1, etc.); medium crop with planting dates between the 5th and 10th of October (Stor's Green F_1, Diamante F_1, etc.); and late crop with planting dates between the 25th of October and 5th of November (Milenio F_1, etc.).
- *Spring cycle*. The varieties Consul and Otelo F_1 are highlighted, which have planting dates from the 1st to 10th of December, as are Cora F_1 and Tosca F_1, which have planting dates between January and February.

The marketed types of courgette can be classified as follows (CAPMA, 2012):

- *Green courgette*. Pepo fruit that is not hollow with an elongated and cylindrical shape and generally light green colour.
- *Other marketed types*. Less marketed courgette, such as round or white types.

Figure 7. Marketed types of courgette

Green Others

Source: CAPMA (2012).

2.3.4. Watermelon

According to the most recent data, there are 5,665 ha of greenhouses (CAPMA, 2012) in the province of Almería that produce 331,811 tonnes of watermelon, which account for 89.5 % of the surface and 73 % of the total production in Andalusia (Junta de Andalucía, 2010). In the 2011/2012 season, the Cajamar Foundation quantified an economic impact of € 102 million.

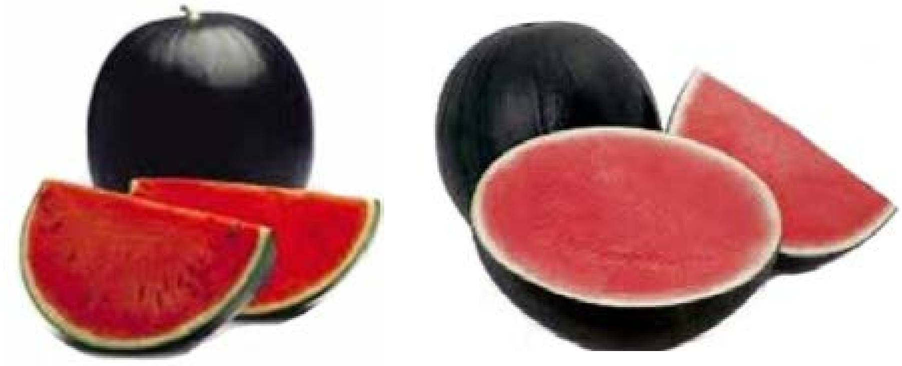
Watermelon (*Citrullus lanatus*, *Citrullus vulgaris* or *Colocynthis citrullus*) belongs to the Cucurbitaceae family and is an herbaceous annual plant of creeping or climbing growth with thin stems that are covered with hairs and have a variable length (Marín, 2013). In addition, 95 % is grown grafted on the C. *maxima* × C. *moschata* pattern, as these patterns are compatible with watermelon, increasing the vigour of aerial part of the plant and providing a highly developed root system (Camacho, 2003). The growth cycle tends to be 3-5 months, and the planting framework tends to maintain distances of 200-400 cm between rows and 50-100 cm between plants (Marín, 2013). The planting framework of grafted watermelon in Almería can be 2 × 2; 1 × 1 o 4 × 1 m^2. Transplantation is usually conducted from mid-November until the end of March (Camacho, 2003). The different varieties of watermelon can be classified into two groups: diploid watermelon and triploid watermelon (Marín, 2013):

- *Diploid watermelon (with seeds)*. This includes all varieties (either smooth or striped) that have well-formed seeds, including the following. (i) Smooth skin and red flesh, with 39 varieties and 1 sub-variety (e.g., Black Pearl F_1, etc.). (ii) Striped skin and red flesh, with 40 varieties and 1 sub-variety (e.g., The Beast F_1, etc.). (iii) Smooth skin and yellow flesh, with 1 variety (Surprise F_1). (iv) Striped skin and yellow flesh, with 1 variety (Angela F_1).
- *Triploid watermelon.* Varieties that do not produce viable seeds because they cease to grow after their development, staying white and tender. They include: (i) smooth skin and red flesh, with 17 varieties (e.g., Passion F_1, etc.); (ii) striped skin and red flesh, with 43 varieties (e.g., Queen of Hearts F_1, etc.); (iii) smooth skin and yellow flesh, with 1 variety (S-10319 F_1); and (iv) smooth skin and yellow flesh, with 2 varieties (Graciosa F_1 and Volga F_1).

The marketed types of watermelon can be classified as follows (CAPMA, 2012):

- *Black watermelon with seeds*. Fruit with an oval spherical shape, black skin, red flesh and black seeds.
- *Black watermelon without seeds.* Fruit with an oval spherical shape, black skin, red flesh, and no seeds.
- *Striped watermelon.* Fruit with an oval spherical shape, striped skin, and red and crisp flesh; can have black seeds, small seeds, or no seeds.
- *Other marketed types.* Less marketed watermelons, such as mini watermelons, yellow watermelons, oval watermelons, etc.

Figure 8. Marketed types of watermelon



Black with seeds

Black without seeds

Striped

Others

Source: CAPMA (2012).

2.3.5. Cucumber

In the 2012/13 season in the province of Almería, there were 4,920 ha of greenhouse cucumber with a production of 411,189 tonnes (CAPMA, 2013a), which accounted for 64.9 % of the surface and 62.9 % of the total production in Andalusia (Junta de Andalucía, 2010). In the 2011/2012 season, the economic impact was estimated at € 169 million (Cajamar Foundation, 2012).

Cucumber (*Cucumis sativus* L.) belongs to the Cucurbitaceae family and is an herbaceous annual plant that grows quickly and is of a creeping or climbing habit, with tendrils that shoot out from knots on the side opposite to the leaves. The growing cycle tends to be 4-6 months, and the planting framework shows spacings of 100-200 cm between rows and 50-100 cm between plants (Marín, 2013). The planting framework in the greenhouses of Almería tends to depend on the crop cycle, with early crops on smaller frames used to increase the density (1.5 × 0.4 or 1.2 × 0.5 m^2). For late cycle crops, or when production is conducted in winter, the planting framework is expanded to avoid competition for light (2 × 0.4-0.5 or 1.5 × 0.5-0.6 m^2) (Camacho, 2003). Three autumn crop cycles can be differentiated: (i) early autumn, with planting in August and harvest from September/October to December/January; (ii) mid-autumn, with planting in August/September and harvest from October to January; and (iii) late autumn, with planting in September/October and harvest from November to March. In addition, there is a (iv) spring cycle, with planting in January and harvest from March to June; (v) extra early autumn cycle, with planting in July and harvest in September and October; and (vi) extra late autumn cycle, with planting at the end of September and harvest from November to the end of March (Camacho, 2003).

The different varieties of cucumber can be classified according to fruit size: snack-type cucumber, short cucumber and gherkin, medium cucumber and long cucumber (Marín, 2013):

- *Snack-type cucumber*. Crunchy fruit, with one variety (Unistars).
- *Short cucumber and gherkin* («Spanish type»). Average length of less than 15 cm, and includes all varieties of small cucumber with green skin or yellow or white striped skin. Used for fresh consumption or pickled, with 31 varieties and 1 sub-variety (e.g., Manolete, etc.).
- *Medium length cucumber* («French type»). Average length between 20 and 25 cm and similar to the Holland type but shorter, with 56 varieties and 11 sub-varieties (e.g., Danito, Victory F_1, etc.).
- *Long cucumber* («Almería type» or «Holland type»). Average length greater than 25 cm; smooth skin, and more or less grooved, with 176 varieties and 20 sub-varieties (e.g., Alcazaba, Galeón, etc.).

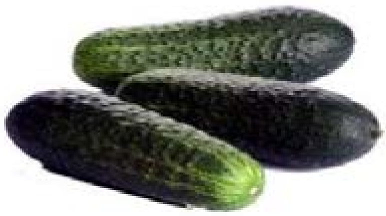
The marketed types of cucumber can be as classified as follows (CAPMA, 2012):

- *Almería cucumber.* Fruit that exceeds 25 cm in length, is dark and straight with smooth skin and generally grooved.

- *French cucumber.* Medium-length fruit (20-25 cm) with varieties whose fruits have spines and whose fruits have smooth skin.
- *Short cucumber.* Small fruit (maximum length of 15 cm) with green skin and yellow or white stripes.

Figura 9. Marketed types of cucumber

Almería French



Short

Source: CAPMA (2012).

2.3.6. Melon

Melon has a significant presence along the coastal plain of Almería, although it has a lower economic impact (at € 51 million in 2011/2012) in the province compared with other crops (Cajamar Foundation, 2012). In the 2011/2012 season, melon was grown in 3,740 ha of greenhouses (CAPMA, 2012), resulting in a production of 141,965 tonnes, which accounted for 90.4 % of the surface and 99.4 % of the total production in Andalusia.

Melon (*Cucumis melo* L.) belongs to the *Cucurbitaceae* family and is an annual plant with creeping habit and highly branched herbaceous stems that grow tendrils susceptible to pruning and trellising. The growing cycle usually is 3-5 months, and the planting framework is spaced with 100-200 cm between rows and 50-100 cm between plants (Marín, 2013). The planting framework in greenhouses in Almería often depends on the variety, growing cycle and characteristics of the greenhouse, with the distance between rows ranging from 200 to 250 cm and spacing between plants ranging from 50 to 100 cm (Camacho, 2003). The melon crop cycles are as follows. (i) Extra early cycle, with transplantation in December/January or even earlier and harvest from March to May. (ii) Early cycle, with transplantation from the end of January to the end of March and harvest from mid-April to the end of June. (iii) Late cycle, with transplantation from mid-February to the end of April and harvest from the beginning of May to the end of July (Camacho, 2003).

The different varieties of melons can be classified according to the following types: yellow, pineapple, branco (white), cantaloupe, Galia, honey dew, Mallorquín, Santa Claus (also known as Piel de Sapo, or Spanish green melon, or toad-skin melon), Rochet, and tendral (Marín, 2013):

- *Yellow.* Oval or round fruit with smooth skin, yellow colour at maturity, non-netted skin, and white flesh, with 43 varieties and 1 sub-variety (e.g., Canary Yellow, Indálico F_1, etc.).
- *Pineapple.* Fruit with orange skin or greyish/green netting and white flesh, with 3 varieties (e.g., Pineapple F_1, etc.).
- *Branco (white).* Fruit with smooth or rough white skin, white or whitish flesh, with 7 varieties (e.g., Divor F_1, etc.).
- *Cantalup.* Round or elliptical fruit that has meridians marked in green and the rest in greyish green and has orange flesh and smooth, semi-netted, and netted skin, with 74 varieties and 11 sub-varieties (e.g., Charentais is smooth, Bosito F_1 is semi-netted and Pistolero F_1 is netted).
- *Galia.* Spherical fruits of green colour that changes to yellow-orange at maturation, dense netting, and white, slightly greenish flesh, with 78 varieties and 2 sub-varieties (e.g., Gaio, Galante, etc.).
- *Honeydew.* Fruit with salmon-coloured flesh, with 2 varieties (Casca de Carvalho and Uncle Sam F_1).

- *Mallorquín.* Rounded fruit that is netted and has yellowish or cream-coloured flesh, with 4 varieties (e.g., Majorca F_1, etc.).
- *Piel de sapo.* (also known as Santa Claus melon (in USA), or Spanish green melon, or toad-skin melon). Oval fruit that is slightly grooved, is green with dark spots, and has white flesh, with 73 varieties and 5 sub-varieties (e.g., Celta, Piñonet Piel de Sapo, etc.).
- *Rochet.* Oval fruit with smooth skin, light green colour and white flesh, with 5 varieties (e.g., Futuro F_1, etc.).
- *Tendral.* Oval fruit with grooved and thick skin of a dark green colour, without netting, and with white flesh, with 5 varieties and 1 sub-variety (e.g., Tendral Tardío, etc.).

The marketed types of melon can be as classified as follows (CAPMA, 2012):

- *Galia melon.* Spherical green fruit that turns yellow-orange at maturity, with dense netting and white slightly green flesh.
- *Cantaloupe melon.* Round or elliptical fruit that has meridian markings that are green and greyish green skin that is smooth or reticular.
- *Piel de sapo.* Elongated elliptical fruit with white flesh that is crunchy and sweet.
- *Yellow melon.* Generally oval fruit with smooth skin and yellow colour at maturity and without netting.
- *Other marketed types.* Less marketed melons, such as the white melon.

Figure 10. Marketed types of melon

Galia Cantaloupe Piel de sapo

Yellow Others

Source: CAPMA (2012).

2.3.7. Eggplant

Eggplant is a crop that reached 2,006 ha of grown surface in Almería during the 2012/2013 season and a production of 145,973 tonnes (CAPMA, 2013a), which accounted for 91.9 % of the surface and 86.5 % of the total production in Andalusia (Junta de Andalucía, 2010). The economic impact of the crop in the province during the 2011/2012 season was € 70 million (Cajamar Foundation, 2012).

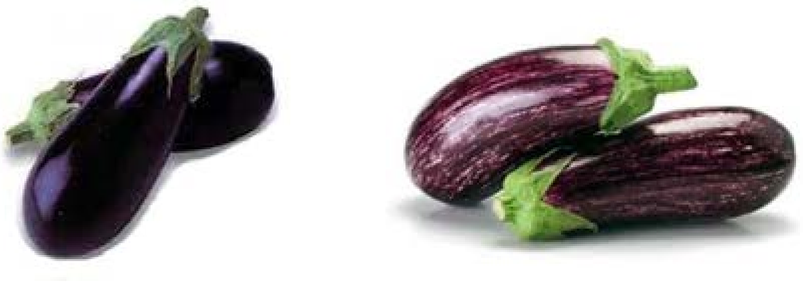
Eggplant (*Solanum melongena* L.) belongs to the *Solanaceae* family, is grown as an annual, and has a semi-woody, erect, branched stem with indeterminate growth. The growing cycle usually is 6-11 months, and the planting framework tends to have spacing of 100-200 cm between rows and 50-100 cm between plants (Marín, 2013). The most common planting frameworks in the province of Almería are 2 × 0.5; 1.75 × 0.5; and 1.5 × 0.75 m^2 (Camacho, 2003). Three crop cycles can be differentiated according to the date of transplantation: (i) from August 15 to September 15, with harvest from October to June; (ii) from August 1 to 15, with harvest from the end of September to December; and (iii) from December 15 to 31, with harvest from March to June (Camacho, 2003).

The different varieties can be classified according to the fruit length (Marín, 2013) as follows. (i) Mini, with 3 varieties (e.g., Eggplant de Almagro, etc.). (ii) Round/oval, with 21 varieties and 1 sub-variety (e.g., black bell, Bonica F_1, etc.). (iii) Semi-long, with 39 varieties and 7 sub-varieties (e.g., Paula F_1, Tizona, etc.). (iv) Long, with 23 varieties and 2 sub-varieties (e.g., snowy white, long purple, etc.).

The marketed types of eggplant can be classified as follows (CAPMA, 2012):

- *Long eggplant.* Fruit that is elongated and narrow, noted for the consistency and nearly black colour.
- *Striped eggplant.* Fruit with mottled skin of purple on white.
- *Round eggplant.* Fruit that is globose, dark, black or violet and shiny.
- *Other marketed types.* Less marketed types of eggplant, such as the snowy melon eggplant.

Figure 11. Marketed types of eggplant



Long

Striped

Round

Others

Source: CAPMA (2012).

2.3.8. Green bean

With 1,283 ha grown in 2012/13 and a production of 24,123 tonnes (CAPMA, 2013a), green bean had an economic impact in the province of Almería in the 2011/2012 season of € 24 million (Cajamar Foundation, 2012), which accounted for 31.1 % of the surface and 22.9 % of the total production in Andalusia (Junta de Andalucía, 2010). Thus, this is the only crop described as having a low percentage in Andalusia.

Green bean (*Phaseolus vulgaris* L.) belongs to the *Leguminosae* family and is an annual plant of rapid development, with a thin stem of determinate or indeterminate growth. The crop cycle is usually 3-5 months, and the planting framework tends to have a spacing of 50-100 cm between rows and 50 cm between plants for low bushes and 100-200 between rows and 50-100 between plants for tall bushes (Marín, 2013). The planting framework in the greenhouses of Almería was traditionally 1 × 0.5 m^2 with 4-5 seeds per planting hole, although this has changed to 2 × 0.5 m^2 with 2-3 seeds per hole, with the plants usually trellised, even at one seed per planting hole (Camacho, 2003). The growing cycles can be differentiated into three cycles: (i) planting in August-September and harvest in November and January; (ii) planting in November-December and harvest from March to April; and (iii) planting in February-March and harvest from May to July (Camacho, 2003).

The different varieties for fresh consumption can be classified according to the type of bush or pod (Marín, 2013) with a total of 156 varieties and 24 subvarieties. (i) Low bush and flat green pod. (ii) Low bush and round green pod. (iii) Low bush and flat yellow pod. (iv) Low bush and round yellow pod. (v) Low bush and round purple pod. (vi) Climbing and flat green pod. (vii) Climbing and flat yellow pod. (viii) Climbing and round green pod. In the province of Almería, the varieties climbing and flat green pod type are primarily grown.

The marketed types of green beans can also be classified as follows (CAPMA, 2012):

- *Flat green bean.* Green bean with a thick or squashed pod.
- *Round green bean.* Green beans with a narrower, round or cylindrical pod.
- *Other marketed types. Less marketed types of green beans that have a very different market value although they belong to the marketed flat green bean type.*

Figure 12. Marketed types of green beans

Flat Round Others

Source: CAPMA (2012).

2.4. Soil management

One of the key factors for the successful development of greenhouse crops is soil management. Intensive horticultural crops have been developed in the province of Almería thanks to the excellent greenhouse and sand-plot system.

The use of sand plots in the greenhouses of Almería is a common practice today. In fact, farmers who grow in organic greenhouses are discovering the advantages of this system (Camacho and Cortés, 2009). In addition, plastic mulches, which use different materials depending on their purpose, are common. However, alternative techniques to the sand-plot system have emerged, such as crops grown in substrates or in hydroponic conditions, due to the difficulties when obtaining sand, problems with soil pathogens, or when very precise nutritional control of the plant is needed.

2.4.1. Sand mulch or «arenado»

The sand mulch (or arenado) consists of covering the surface of the crop field with a layer of silica sand, which retains moisture. In Almería greenhouses, however, the development of this soil type is more complex.

Once the natural terrain of the plot has been cleared and levelled, it is covered with an initial half metre-layer of soil with a high clay content, which is extracted from areas of fluvial sediment accumulation (ravine soil). If the same qualities as that of the clay soil are found in the soil of the plot, this layer is not added. This layer will prevent major losses of irrigation water caused by deep percolation because of its impermeability and high moisture retention capacity. This layer also prevents the roots from reaching the bare soil area.

Over the clayey soil, a second layer of manure or organic matter is placed, which will constitute the habitat for the development of the root system of the plant. This layer also acts as a buffering element to correct possible deficiencies in fertilisation.

Figure 13. Diagram of a sanded soil

Finally, the plot is covered with a fine layer of sand with an average particle size less than 3 mm in diameter; this sand was originally from breakwater beaches or dunes and is currently extracted from quarries.

Camacho and Cortés (2009) summarised the advantages contributed by sand mulch:

- Increases the intensity of microbial activity, leading to a premature harvest.
- Improves the use of mineral fertilisation by plants.
- Improves the solubilisation of the fertilising elements contained in or provided to the soil.
- Contributes to increased CO_2 concentration near the ground, acting as a carbon fertiliser.
- Conserves soil moisture for a longer period of time, which saves irrigation water.
- Prevents the ascension of salts to the lower soil levels, thus achieving permanent desalination.
- Maintains the structure in excellent condition for longer periods.
- Favours the development of roots on the surface.

The main drawbacks of sanding are as follows:

- Represents an additional cost, since an external contribution of land is necessary.
- Increases the difficulty of soil work, which should be performed manually to avoid mixing different strata that constitute the soil.
- Improves soil conditions that also favour the development of pathogens.
- Favours the development of weeds and hinders their disposal, increasing the cost of weeding by hand.

The fertility of sand plots decreases over time as plants remove the nutrients contained in the layer of organic matter; therefore, the replacement of the organic matter is required. In the greenhouses of Almería, there are two different techniques for the replacement or renovation of manure: broadcasting and banding.

Figure 14. Tomato crops in a sanded traditional greenhouse

Broadcasting

In greenhouses using the sand-plot technique, it is common to replace the manure over the entire greenhouse surface every 5 or 6 years. This work is called retranqueo, or broadcasting. The first step is to remove the sand that covers the fertile layer of soil in stripes or furrows of approximately one metre and that is accumulated to the sides in ridges. This process must be performed carefully to avoid mixing of the layers and prevent contamination of the sand with impurities. This work is usually performed manually using broad-bladed hoes; in some cases, it is conducted with tractors with ploughs (Figure 15), which is locally known as aparta-arenas, or sand-separator, because it allows the sand layer to be opened without reaching and mixing with the lower stratum.

Once part of the sand has been removed, the exposed soil of the furrows is ploughed to till the manure layer with the ravine soil, promoting its aeration. This work is usually performed with cultivators or tractors with milling tools that crumble the soil and facilitate the incorporation of organic matter.

After tilling the soil, manure is deposited and spread in the furrows, with certain farmers using a small shovel that is coupled to the tractor, which facilitates the work. In certain cases, farmers take advantage of the manuring process to conduct deep fertilising with phosphorous and potassium compounds. The sand is then collected from the ridges and spread over the manured area, and the entire process is repeated on the other side by removing the sand from the furrows and piling it in the rows where the manure has already been renewed.

Figure 15. Ploughs or «sand-separators»

Banding

Because of the high cost of broadcasting the manure over the entire plot and the excessive time required to conduct the procedure, some farmers have opted to apply carillado, or banding, in strips. This technique is similar to broadcasting because it is also replaces the manure, although only in the lines where the plants are located. Thus, it is only necessary to open a small 30-50 cm wide ditch located in the area where the plants will be placed during their transplantation.

For each round of banding, the furrows where the crops will be planted are alternated with those where the banding has been conducted, which reduces the renewal period of the manure as well as the cost and time invested. Another current trend is to contribute organic matter of vegetable origin instead of applying manure because of the problems with manure being too strong or having an unsuitable fermentation state. This practice is usually performed every 2 or 3 years, although it is less common than broadcasting.

2.4.2. Plastic mulching

Plastic mulching is commonly used to increase the harvest both quantitatively and qualitatively because it promotes early maturity, provides weed and insects control, and increases the efficiency of water and fertiliser use (Lamont, 1993). In addition, mulching reflects radiation, thus increasing the radiation available at the plant level, provided that a suitable plastic material is used, depending on the purpose of the mulch.

The use of an impermeable mulch is essential to reduce water loss from the soil by evaporation, which, in addition to increasing the consumption of irrigation water, also increases the relative humidity in the interior of the greenhouse. Because indoor humidity must be controlled in greenhouses to prevent the development of fungi and diseases and ventilation is restricted by heat loss, the plastic mulching technique may be highly recommended.

In addition to preventing water evaporation, there are other advantages to using plastic mulches, such as preventing the proliferation of weeds, redirecting CO_2 output from the decomposition of organic matter towards the holes where the plants are housed, and facilitating the absorption of CO_2.

Mulching materials are usually PE sheets with a 150 or 200 gauge thickness that are black or, in some cases, transparent. The mulches can cover the entire greenhouse or only the lines where the plants are located.

Figure 16. Greenhouse with black polyethylene mulching on the entire surface

2.4.3. Soilless crops

The definition of so-called soilless crops is quite broad and includes all the methods and systems that produce plant growth outside the natural environment of plants, which is soil (Urrestarazu, 2000). Because of the need to maintain tighter control of the growing conditions, soilless growing techniques are currently used in Almería greenhouses. If well-managed, and although they may pose an additional risk of failure such as failure of the electrical system, they can achieve increased production and reduce the labour associated with tilling. Such techniques also allow for the complete automation of fertigation, although precise control of its management is required because any minor error related to deficiencies or excesses of nutrients can cause damage to the field because the regulating effect exerted by the soil is suppressed.

Substrate growing is the replacement of the soil by a porous material that enables the root system to develop. Nutrients are provided by a nutrient solution that contains suitable concentrations of each of the essential elements for optimal plant growth.

In the next sections, we will briefly describe several of the most commonly used substrates, including hydroponics, where the roots are directly in the nutrient solution.

Peat

One of the primary substrates used as a culture medium is peat, which is formed by incomplete decomposition of a large plant mass caused by an excess of water and a lack of oxygen. Peat is a natural substrate with excellent physico-chemical and biological properties that provide a stimulatory effect on growth, possibly because of the presence of soluble humic substances and hormonal compounds from the non-decomposed plant remains. The use of peat is limited by its biological and natural origin because areas where it is extracted are not renewable, which causes serious effects to the environment if continuously removed. Other drawbacks are its heterogeneity and the possibility of negative interactions with the elements dissolved in the nutrient solution, which can lead to excesses or deficiencies by the release or retention of certain compounds.

Rockwool

This substrate is composed of mineral wool fibres made from diabase rocks that are mixed in a casting process at high temperature (1,600 ^{0}C) with limestone and coal. Rockwool (Figure 17) has a compact physical structure that is dependent on the arrangement and density of the fibres.

This product is sold as boards with dimensions usually around 100 × 15 × 10 cm^3 and fibres running horizontally and vertically. The vertical fibres have better characteristics than the horizontal fibres because they have higher density and rigidity and high capillarity, which results in a better distribution of water in the entire table, improved saturation capacity and less drainage.

Figure 17. Growing of peppers in rockwool boards

Perlite

Perlite is an aluminium silicate from volcanic rocks. Through a process of fragmentation into small particles using mills and high treatment in furnaces (to 1,000 ^{0}C), the changed water, which contains the natural rock, is eliminated (2-5 %), resulting in a particle expansion that can reach up to 20 times its initial volume.

This substrate is an inert material with high porosity and a high capacity of water and nutrient retention, which makes it an ideal medium for plant growth and root development. Perlite is usually sold in 28-to-40 litre plastic bags with micro-perforations at the top to encourage aeration, and it can also be used in small containers, which allows for granulometric stratification grading of its particles, or prepared in bulk in growing trays where the nutrient solution circulates.

Expanded clay

Expanded clay (Figure 18) is obtained from natural clay that is baked in a rotary kiln at 1,200 ^{0}C. During the process of forced evaporation, the clay structure is expanded. Using this method, the clay acquires a greater capacity to absorb water, its durability is improved, and its specific weight is reduced.

This type of substrate has good drainage, which reduces the accumulation of salts and waste and allows it to be used with low-quality water.

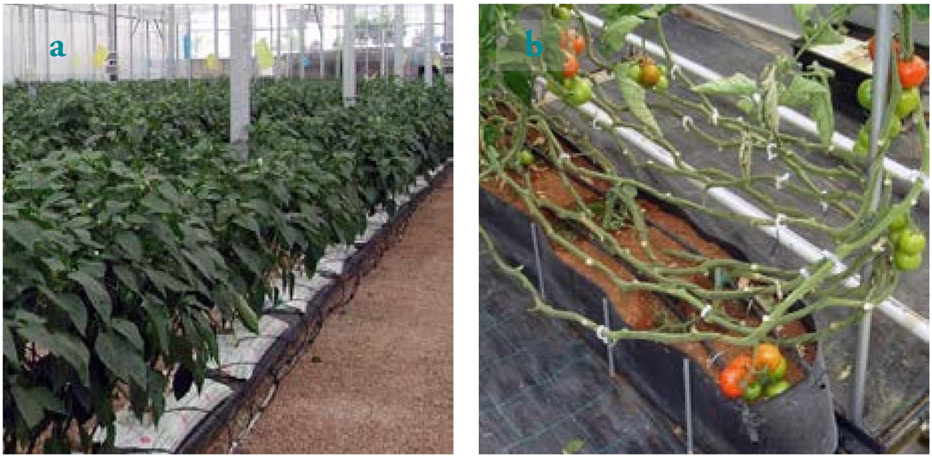
Figure 18. Growing of peppers in sacks of expanded clay

Coconut fibre

This substrate consists of fibres of the coconut shell. It has high porosity and high water retention capacity with good drainage, and unlike rockwool or perlite, it has a high cation exchange capacity (CEC). It is sold similarly to perlite, being available in sacks (Figure 19a) as well as in bulk for use in containers or trays (Figure 19b).

The main advantage of this substrate is its low environmental impact because it is obtained as a by-product of coconuts, and as it is biodegradable, its disposal is not as problematic as that of mineral substrates.

Figure 19. Growing of pepper in expanded clay sacks (a) and tomato in coconut fibre containers (b)



Hydroponics

Hydroponics consists of techniques used to grow plants without any solid substrate. Under this technique, the root system is developed in an aqueous medium with dissolved nutrients and the necessary elements for the proper development of plants. There are several methods of hydroponics, including the Nutrient Film Technique (NFT). This technique consists of maintaining the plant over a channel in which a thin film of nutrient solution flows, with the roots developing by contact with the liquid. Distributing the root system over a small volume of liquid relative to the surface produces a perfect aeration of the roots.

The most commonly used channels are usually 200-gauge PE, which must be opaque to prevent the development of surface algae. This system has advantages over other types of soilless growing systems, such as the simplicity of its structure, which consists of simple plastic channels and allows for good aeration of the roots. However, the main differences are that in this system, there is a continuous recirculation of nutrient solution, although this is also possible in substrate crops.

The recirculation of nutrient solution is an effective alternative to water shortages and environmental problems resulting from the elimination of drainage waters with high levels of chemical elements. This system results in a better use of resources, physical space, water, and fertilisers, and certain phytosanitary treatments can be applied in the solution.

Soilless crops provide additional benefits since they facilitate tilling and they allow for growing at various heights, thus optimising land use. Furthermore, they enable advanced techniques for growing plants in different development stages in the same greenhouse. All of these factors increase the control of the water and nutrient supply to the plants and allow for proper management of the leachate.

2.5. Greenhouse structures

Gradual advances in phytosanitary matters, plant breeding, growing techniques and marketing have accompanied the rapid development of greenhouse crops. However, until the end of the 1990s, these developments had not produced an improvement of greenhouse structures and climate control, which was primarily due to the length of time and investments required to renovate the structures (Valera *et al.*, 1999b). Today, there is still much room for improvement in greenhouse structures and climate control, in addition to other priorities such as plant breeding for improved flavour, waste management, and measures to revert the declining trend of farmers' incomes.

However, the incorporation of technology into greenhouses in the last ten years has shown significant but slow progress, with the introduction of active climate control systems and, to a much lesser extent, equipment for the analysis of production and labour management. Throughout this process, slow-paced improvements have been made to the structure of the greenhouses. Thus, there has been a progressive abandonment of the traditional parral, or flat-type structures. Today, improved derivations of traditional greenhouses have been constructed, with greater interior volume, better airtight conditions, and gabled inclinations for each module: the 'raspa y amagado' type, which permits the installation of roof ventilation and other improvements. In addition, the surface of multi-span greenhouses continues to increase. These greenhouses provide greater interior volume, have increased ventilation surfaces as a result of the roof and side windows in all four bands, have better airtight conditions, and provide greater possibilities of incorporating active climate control systems. However, each technological improvement is justified only if an anticipated increase in the profitability of the agricultural holding is guaranteed, which is also decisively determined by crop type and marketing. Such considerations inspired the special interest of this study.

As previously mentioned, greenhouses from other European countries are also gaining ground, such as the multi-span type used in France and *Venlo* greenhouses from Holland. The original design of these structures was less adapted to the climatic conditions of the area than that of the Almería-type greenhouses. The *Venlo* (or glass) greenhouses have been introduced along the peninsular southeast in the last agricultural seasons primarily by Dutch capital enterprises. The essential problem with this type of greenhouse is its high cost, which is another order of magnitude higher than that of the traditional Almería type and industrial or multi-span types.

All the new structures are more airtight and higher, have greater thermal inertia, and possess greater separation between supports, which allows for the incorporation of new equipment and technologies, greater control of environmental parameters, and introduction of mechanised tillage.

As a result of the emergence of European standards for greenhouse construction, as well as those already applicable in Spain, such as the requirement of metal structures (UNE 76-208/92), greenhouses must adapt to improve their safety against wind damage and allow for greater climate control. Attempts have been made (without the expected success) to create a UNE standard for the construction of Almería-type greenhouses, mainly with a vision to improve the resistant elements that compose the structure, ensure the quality, and facilitate the export to other countries and climatic zones (South America, North Africa and East Asia). Standardisation must provide greater homogeneity in the designs, greater structural safety, and an easier method of incorporating technology that is primarily oriented to climate control.

In Holland, new designs of *Venlo* type greenhouses are being marketed with two floors and a height greater than 8 m, and they include sophisticated climate control systems that make closed greenhouses possible. In these greenhouses, twice the planting density can be achieved because the crop can be grown at two different heights. On the lower floor, continuous artificial lighting is used, whereas on the upper floor, solar radiation is used. In addition, the temperature is controlled by heating and recirculating hot air from the top to bottom floors.

In all cases and for all the above-mentioned greenhouse types, the microclimate is dependent on factors inherent to the structure, exterior climate and crop type.

The first factor to be considered when building a greenhouse is its orientation because it determines the availability of light for plants and determines the effectiveness of the ventilation system and the safety of the structure against wind. The type of greenhouse and shape of the roof mainly affect solar energy capture.

One of the most important geometrical characteristics of a greenhouse is its width because this directly affects internal circulation. It is also important to consider greenhouse height in the design because it determines the unit volume. In Mediterranean greenhouses, the design parameter.

2.5.1. Almería-type greenhouse

The Almería-type greenhouse has different subtypes, such as parral, or flat-top; 'raspa y amagado'; and asymmetric, although the structural differences are very small. For this reason, all three are known as Almería type because of their place of origin from which they expanded to other areas of the Iberian Peninsula and other continents, such as North Africa, America and parts of Asia.

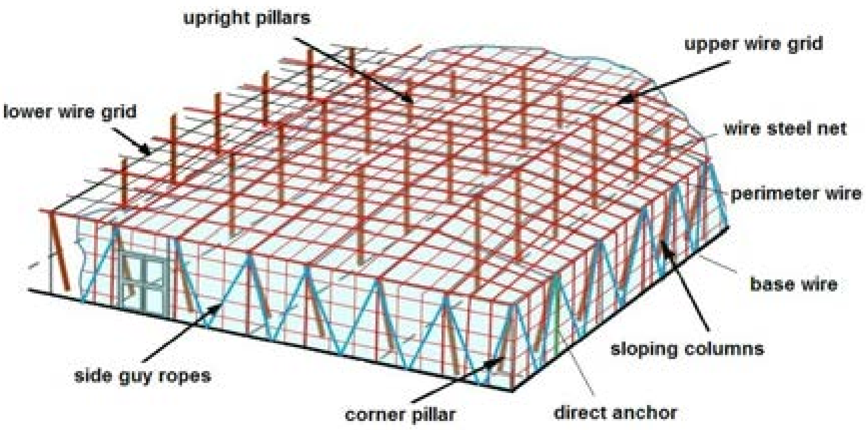
Most of the greenhouses in the province are of the Almería type. These greenhouses are characterised by the flexibility of the structural elements, which are composed of individual wires or braids that are subject to initial tension during the process of construction (Valera *et al.*, 2004). The roof closing consists of flexible plastic sheets between two wire grids, with the sheeting extending to the sidewalls of the structure. In the southeast of Spain, these structures are the most popular. Three subtypes of Almería-type greenhouses can be differentiated depending on the shape of their roof:

- *Parral plano or flat-top*: Almería greenhouse with a flat cover of plastic that is perforated to allow entry of rainwater.
- *'Raspa y amagado'*: Almería greenhouse consisting of gabled modules with interior modules that have symmetry with respect to the ridge. Along the perimeter, the slope of the outer skirt is different from that of the interior.
- *Asymmetric*: Almería greenhouse formed by two gabled modules with asymmetrical interior modules with respect to the ridge.

Flat-top greenhouse

The first subtype is the parral plano, or flat-top, greenhouse, which is derived from the old arbours parrales dedicated to the growing of table grapes. This structure is composed of two basic elements: one vertical structure and one horizontal structure (Figure 20). The vertical structure consists of rigid supports that can be differentiated according to their location along the perimeter (sloping colloums located in bands and corners) or indoors (known as upringht pillars).

Figure 20. Structure of the flat-top greenhouse



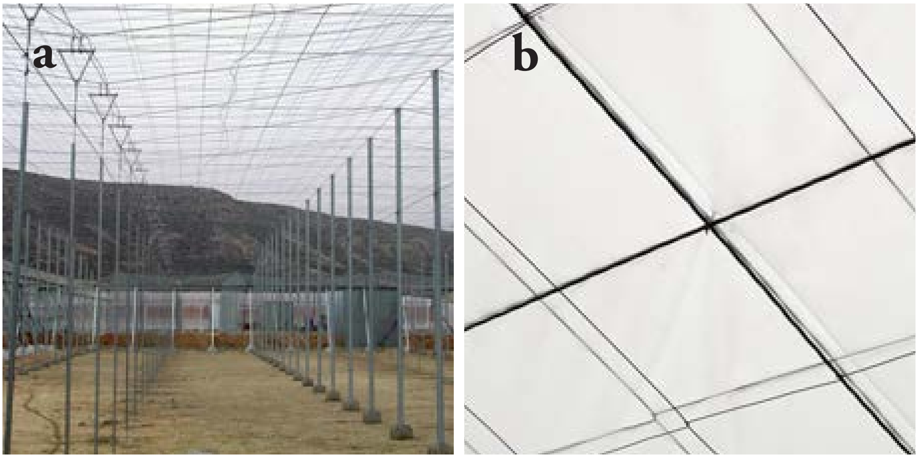
The vertical supports of the interior are responsible for transmitting loads to the foundation. The centre posts define the height of the greenhouse. The upright pillars are often separated by 2 m longitudinally and 4 m laterally, although they can also be separated by 2 × 2 and 3 × 4 m. The posts can also be «staggered», i.e., alternating the support layout in each line.

Sloping colloums along the perimeter of the greenhouse define the height of the bands. These perimeter supports tilt outward from approximately 30^0 to the vertical and along the direction of the winds, and the upper end is fastened to the ground, which serves to tighten the wire cables of the cover. These supports generally have a separation of 2 m, although distances of 1.5 m are also used.

Both the exterior and interior supports may be composed of pine or eucalyptus logs, galvanised iron pipes, rolled iron, or, rarely, pre-stressed concrete poles. The vertical closure of the greenhouse is composed of bands whose main structural element is the «ruedo».

The flexible horizontal structure (flat) is composed of two overlapping galvanised wire grids that are manually woven to the construction of the greenhouse (Figure 21). These two grids (or «fabric weaves») are formed by a quadrangular set of threads and cords, which are the resistant elements of the roof structure and bands. There are two fabrics (upper and lower) that support and hold the sheet of plastic between them (Figure 22a).

Figure 21. Structure of the Almería-type greenhouse with double wire grids (a), and detail of the union of the longitudinal and transverse ropes (b)

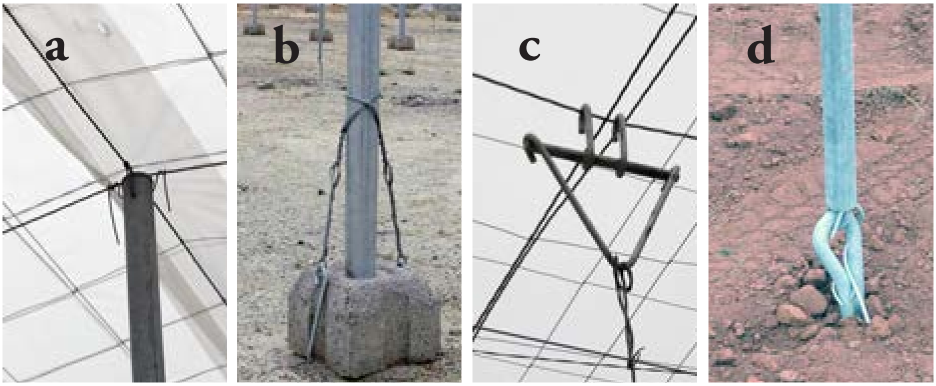


The main resistant elements of the cover fabric are the ropes (Figure 21b), which are composed of thick wire that is braided or cabled. The ropes are fastened to the centre posts using a wire knot with a minimum of four wraps called «garrotera», or crook knots (Fig 22a).

The top and bottom fabrics between which the plastic sheet is placed are joined by a wire point that pierces the sheet (Figure 21b), thus reducing the airtightness of the greenhouse, which is one of the major drawbacks of these types of structures.

In addition to these two structural components, there are other elements of the greenhouse, such as precast concrete blocks, whose upper face is hollowed to support the centre post of the greenhouse (upright pillars) and transmit the compression efforts to the foundation or directly to the ground. The greenhouses are currently built on concrete piles that are manufactured on-site, with the foundation finished with a reinforced «U», within which sits the concrete that supports the upright pillars. A wire attaches the upright pillars and reinforces the foundation (Figure 22b).

Figure 22. Structural elements of Almería-type greenhouses: union of the longitudinal and transverse ropes to a upright pillar using crook knots (a), anchor pillars (b), channels fastened to the transverse ropes (c), and cension braces anchored to foundations (d)



Most of the greenhouses that are built today are reinforced with stability braces, which utilise iron rounds welded to the top of the pillars of the perimeter instead of the traditional wire rope, and a perimeter fence made by welding steel angles at the top of the sloping columns (Figure 23a). The stability braces are resistant elements that act as tensioning elements, joining the upper part of the sloping columns and foundations. Each of these tensioning elements forms an acute angle with respect to the vertical (Figure 23a). In addition, «direct» anchors located perpendicular to the terrain can be added to join the base perimeter strap with the upper part of the sloping columns and top perimeter strap (Figure 23b). Both the direct anchors and stability braces are anchored to foundations. The set of cables on the same post is referred to as a fan (Figure 23b). All these anchor are an extension of the foundation frame.

Figure 23. Structure of the lateral band of an Almería-type greenhouse with top perimeter, strap of steel angles and steel stability braces (a), and detail of a direct anchor between two stability braces (b)

A particular type of flat-top greenhouse consists of a structure of iron galvanised pipes spaced 3 x 3 m apart (Figure 24). This is an older-tyoe of greenhouse in which the perimeter supports are placed vertically, and its height is approximately 2.5 m.

Figure 24. Inside of an older-type of flat-top greenhouse with a metal structure

The main advantages of this type of greenhouse are as follows:

- It is very cost effective, with a price between 4 and 10 €/m^2 depending on the type of support.
- It can adapt to different plot shapes as well as uneven terrain.
- It provides uniform light.

The disadvantages of this type of greenhouse are as follows:

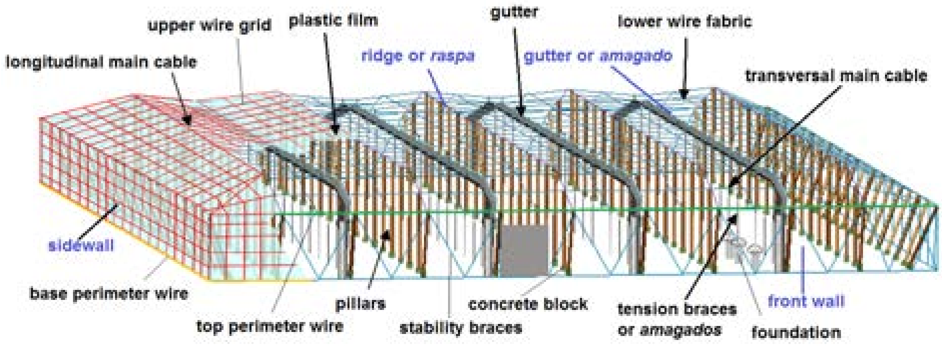
- It has a large number of obstacles inside, so free space is scarce.
- The ventilation is poor when the width is greater than 30 m, which happens in most cases.
- The installation of roof vents openings is difficult.
- It is not particularly rainwater- and airtight, which causes high humidity inside and possible crop damage from dripping during rainy periods as well as high heat loss from indoor air leakage.
- Its lack of airtightness prevents the incorporation of climate control techniques.

'Raspa y amagado' greenhouse

The distribution of this type of greenhouse has expanded the most in recent years to the detriment of the flat-type greenhouse. The structure is similar to the flat-top type and primarily differs according to the shape of the roof, which is angled from 6º to 20º. The more increased the angle, the better the interception of solar radiation, although it requires greater structural strength because of the effects of wind action. The cover consists of the following two parts (Figure 25):

- The *raspa*, which is the intersection of the two sides of the roof of the module at its highest part.
- The *amagado*, which is the intersection of the bottom sides of the roof between the adjacent modules where rainwater gutters are installed.

Figure 25. Structure of an Almería-type greenhouse



With respect to flat-top greenhouses, the maximum height of the greenhouse is at the ridge and ranges between 3 and 4.2 m, which forms the raspa. The amagado attaches the cover grids to the soil by cables and iron forks that allow for placement of the gutter. The height of the amagado ranges from 2 to 2.8 m, and the bands are between 2 and 2.5 m.

In the 'raspa y amagado' type, the separation between the pillars and tension braces of the threads is usually 2 × 4 m, although separations of 2.5 × 4, 2 × 6 or 2 × 8 m are also used. In the structure of these greenhouses, a longitudinal main cable runs parallel to the raspas, or ridges, of the greenhouse that rests on studs, and a transversal main cable runs perpendicular to the longitudinal raspas. In addition, the wire grid fabric is made up of smoothing threads parallel to the raspas as well as woven threads perpendicular to the raspas of the greenhouse, which are turned over the smoothing threads.

Figure 26. 'Raspa y amagado' variety of the Almería-type greenhouse

In addition to its great adaptability to Almería conditions, the expansion of this greenhouse has resulted from the following factors:

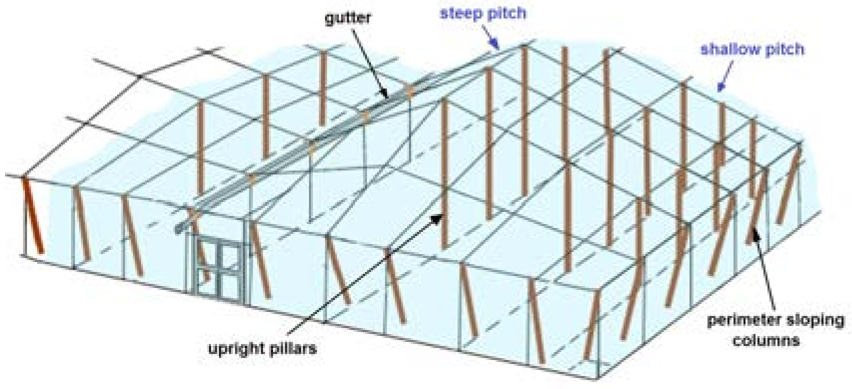
- It is cost effective, with the cost of construction at 4.5-15 €/m^2.
- It has a good unit volume and greater thermal inertia, which increases the temperature at night and hermetic character compared with flat-top greenhouses.
- It has a greater height, which facilitates air circulation.
- It permits the installation of roof ventilation placed to the leeward side, next to the edge of the ridge, which allows for good ventilation through the *chimney effect*.
- It provides good resistance to wind action.
- It can accommodate irregular geometries of the plot (imbalances), similar to other Almería-type greenhouses.
- It is well-adapted for certain crops, such as non-trellised crops

Figure 27. 'Raspa y amagado' greenhouse under construction

Asymmetric greenhouse

The asymmetric variety (Figure 28) differs from the 'raspa y amagado' subtype because the sides of the cover have different slopes to enhance the capture of solar energy. In this subtype, the ridge height varies between 3 and 5 m, and the gutter height is 2.3 to 3 m. The height in the bands varies between 2.15 and 3 m. The separation of interior supports is usually 2 × 4 m, although values of 3 × 4 and 2 × 8 m can also be found.

Figure 28. Structure of an asymmetric greenhouse



2.5.2. Multi-span greenhouse

The multi-span greenhouse, which is also known as an industrial-type greenhouse, is characterised by the semi-cylindrical shape of its roof and all-metal structure (Figures 29 and 30). This type of greenhouse is currently expanding in agricultural holdings with greater technical investment because of its improved ability to control microclimatic variables.

Models of multi-span greenhouses consist entirely of galvanised steel pipes that are mostly cylindrical at the cross section, 25 to 60 mm in diameter and 1.5-3 mm thick. Brackets or clamps join different pieces, which are cold-shaped by cutting and pressing 1.5-2.5 mm thick galvanised sheets and screws.

In these greenhouses, plastic is fastened to the structure by means of profiles known as «omegas» because of the shape of their section (Figure 31). The ends of the plastic are inserted into the hollow part of the unit and are secured by PE blocks, which exert a strong pressure on the inside of the metal profile.

Figura 29. «Multi-span» greenhouses of the University of Almería

Figure 30. Structure of a «multi-span» type greenhouse

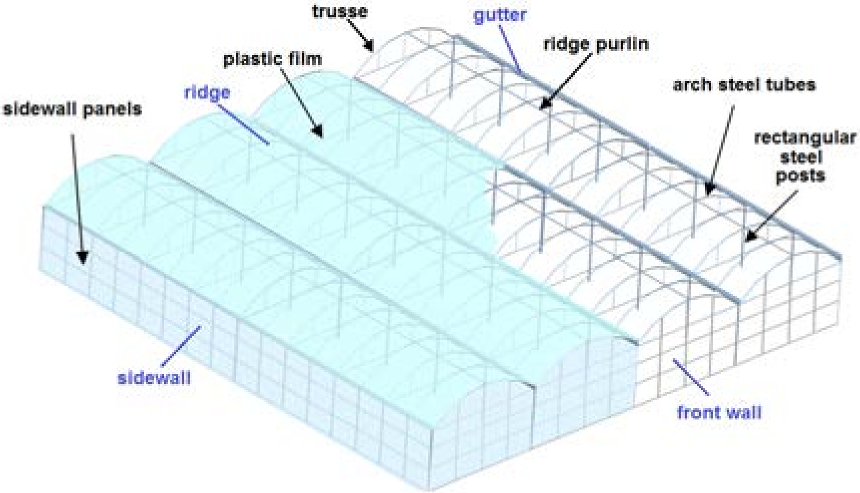


Figure 31. Omega profiles for the attachment of plastic in multi-span greenhouses

The typical wire networks used in Almería structures have been eliminated in these greenhouses. To better fasten the plastic, plastic ribbons or threads can be placed on the outside to keep the cover attached to the structure and prevent flapping of the film on the metal structure during strong winds, which often result in cutting and breakage.

The spams have widths ranging from 6.5 to 9 m, and the separation between internal pillars tends to be 4 or 5 m. The most widely used framework has an 8 x 5 m separation of the interior supports, whereas that of the older greenhouses is 3 x 5 m. The maximum height of these types of greenhouses is usually between 3.5 and 5 m, and the side walls can be as high as 2.5 to 5 m. The trend is to build them increasingly higher and include roof (in all spans) and lateral ventilation around the entire perimeter.

Many of the greenhouses of this type are built with a rigid lateral enclosure of corrugated polycarbonate (PC), which provides greater wind resistance on the sides and front, where wind action is higher. The cover is low density PE, similar to that used in the Almería-type greenhouses.

Figure 32. Structure of a cylindrical covered multi-span greenhouse

Advantages of greenhouses with semi-cylindrical cover are as follows:

- It provides a large separation of supports so that machinery can enter in the greenhouse and mechanised work can be performed.
- It has a greater height, which facilitates air circulation.
- It has good water and airtightness that allows for active climate control methods, such as heating, pad-fan-cooling evaporators or carbon enrichment.
- It allows for the installation of downward roof ventilation, which increases the rate of ventilation and facilitates mechanised action.
- The curve of the cover provides a good amount of brightness in the interior of the greenhouse.
- It allows for part of the structure to be used as a receiving area or storage area.

Its principal drawbacks are as follows:

- It has a high cost of construction, approximately 12-25 €/m^2.
- Its plastic cover requires greater mechanical demands because it is not strongly attached to the structure.

A variant of the indoor circular-cover multi-span greenhouses is the ogival or gothic type greenhouses, in which the arches consist of two circumference arches that are welded to the ridge (Figura 33).

Figura 33. Gothic-type multi-span greenhouse with «superzenith» windows in the ridge

2.5.3. *Venlo* type greenhouse

The *Venlo*-type or glass greenhouse (Figure 34) is a typical structure used in the Netherlands, although a number are found in Almería.

These greenhouses are formed by a metal structure and ridge in the shape of a multiple chapel with a slope of 22^0 in the majority of cases. These greenhouses have a solid structure capable of withstanding the heavy weight of the glass plates that constitute the enclosures.

The standard thickness of the glass is 4 mm, with a maximum width of 1.125 metres, and the glass panes are fastened on four sides. The use of a trellis truss increases the width of the modules to between approximately 6.4 and 12 m. pillars can have a separation of 3.4 or 4.5 m, and the height of the roof ridge can reach 6.5 m. The essential problem with this type of greenhouse is its high cost, which is an order of magnitude higher than that of the traditional flat-type and industrial or multi-span greenhouses. These structures are also designed for use in cold areas

These greenhouses have been effective in the cold climate of central Europe, which is their area of origin, but their adaptation to the harsh summer climatic conditions in arid areas, such as Almería, as well as the cost of installation, which is much higher than that of other types (approximately 30-40 €/m^2), has limited their expansion in these areas.

Figura 34. Structure of a *Venlo* type greenhouse

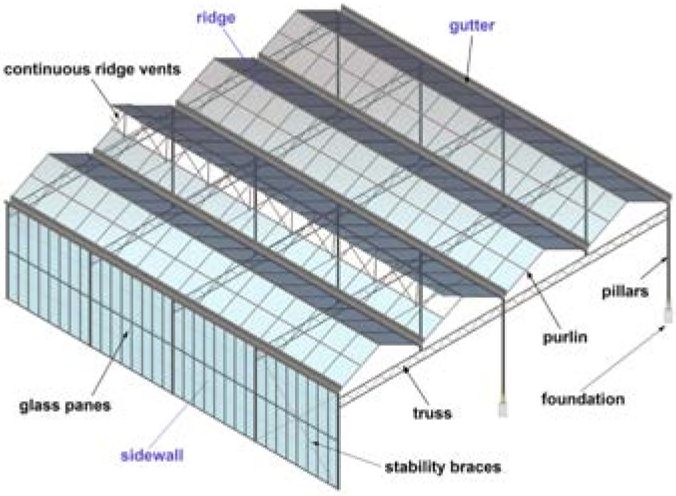


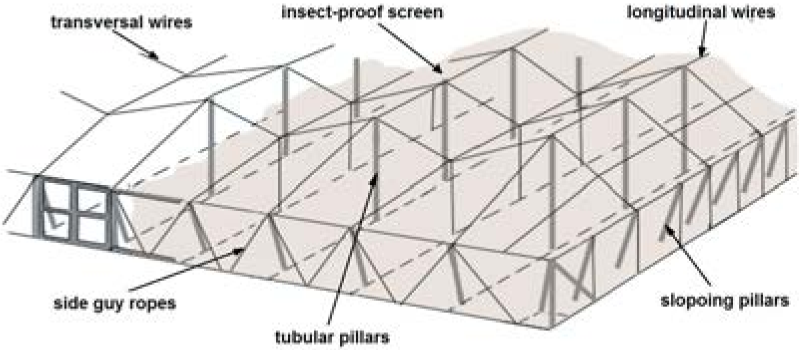
Figura 35. *Venlo* type greenhouse in Almería

2.5.4. Screenhouse

Mesh-covered greenhouses or screenhouses have been successfully used for growing tomato on the Canary Islands, and they have also been implemented in the Bajo Almanzora region of Almería, especially for tomato.

These greenhouses have a similar structure to that of 'raspa y amagado' greenhouses, include supports entirely composed of galvanised iron tubing, and have a ridge height of 4 m and an interior separation of 3 x 4 m. The slope of the cover is about 22^0.

Figura 36. Structure of a mesh greenhouse



The advantages of using mesh-covered greenhouses are as follows:

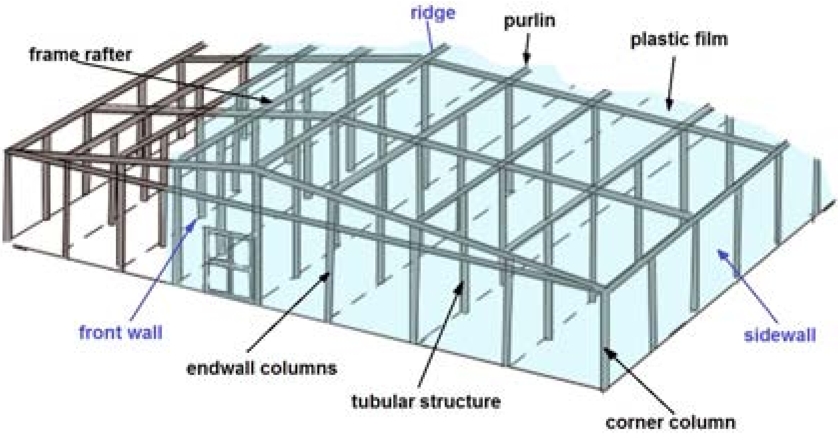
- Its height and cover permeability provide better air circulation.
- It makes the most of rainwater.
- It has a large separation of the supports that facilitates work and machinery in the greenhouse.
- It provides great resistance to high winds.
- It has a low cost of construction of approximately 10-14 €/m^2.

Figura 37. Screenhouse with tomato crop

2.5.5. Plastic-covered «gabled» greenhouse

The plastic-covered «gabled» type of greenhouse is an old type of structure that tends to disappear with further advancement of other types of structures. Construction of this type of greenhouse has been reported with sticks, wires, and galvanised iron pipes. The latter are known as the «Canary Islands» type because their use is widespread on the islands.

Figura 38. Structure of a greenhouse with galvanised iron pipes and «gabled» cover



The separation of the interior supports is usually 2 × 4 m for wood supports and 3 × 3 mm for metal structures. The height of these greenhouses is 2.3 to 4 m at the ridge and 1.8 to 2.2 m at the bands. The slope angle of the roof ranges between 2 and 10^{0}.

Figura 35. Greenhouse with «gabled» cover

2.5.6. Geometric characteristics of greenhouses

The microclimate that is generated inside of a greenhouse depends on the outside climatic conditions, crops being grown, and a series of factors and characteristics of the greenhouse itself that depend on its design and remain unchanged throughout its life. Following are several of these characteristics:

Location

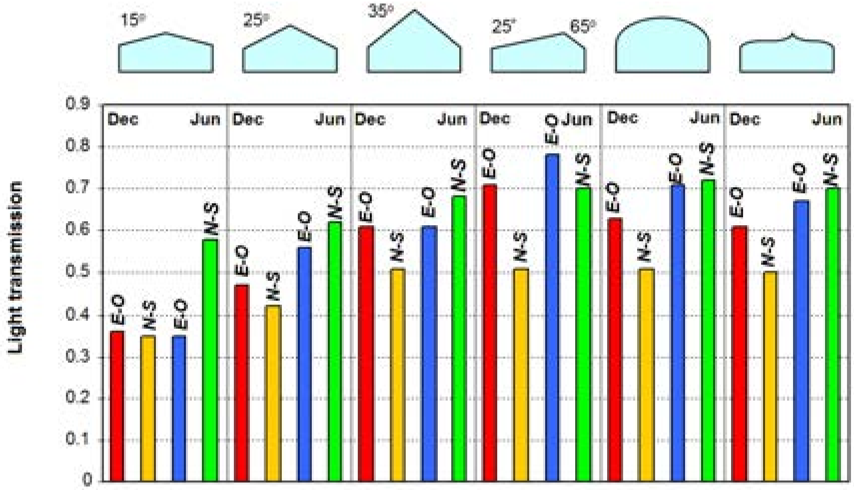
The first factor to be considered when building a greenhouse is its geographical location. Humid and shady areas should be avoided along with locations excessively exposed to the direct action of strong winds and areas where the presence of other greenhouses can hinder ventilation, which is the principal method of climate control in greenhouses in Almería. Other considerations relate to proximity to roads, availability of water and electricity, cost of the land, etc.

Orientation

Another factor to be considered when building a greenhouse is the structure's orientation because it determines light availability for plants, effectiveness of the ventilation system and safety of the structure in relation to wind. Considering the winter season only, which is the period of the year with the lowest light intensity and shortest days, at latitudes greater than 30°, which is characteristic of Almería, an east-west (E-W) orientation (Figure 40) ensures a greater coverage of solar radiation transmissivity than a north-south (N-S) orientation (Urban, 1997; Giacomelli and Ting, 1999). Greenhouses with high cover slopes (30°) have a transmissivity of global radiation in autumn and winter that is up to 10 % higher in an E-W orientation compared with a N-S orientation (Castilla, 2005). This result was observed by Bot (1983) with *Venlo*-type greenhouses, which showed transmissivity values of 45 % for the E-W direction and 35 % for the N-S direction in December. However, for the Almería-type greenhouses, whose average slope is 7.2° (Molina-Aiz, 1997; Valera *et al.*, 1999b), there is practically no difference in transmissivity between the E-W and N-S orientations (Papadakis *et al.*, 1998; Castilla, 2001).

For ventilation, the best orientation is perpendicular to the prevailing winds in spring and summer when the requirements for ventilation are greater. For this reason, depending on the plot, it is common in Almería to place the axis of the ridge of the greenhouse in the N-S direction. Thus, the roof windows are perpendicular to the prevailing western and eastern winds in the area. The incidence angle of the wind over the windows would not appear to have a significant effect in the *Venlo*-type greenhouse with discontinuous windows (Fernández and Bailey, 1993; Campen, 2003), multi-span greenhouses (Boulard and Draoui, 1995) or Almería-type greenhouse (Campen and Bot, 2003) with continuous windows along the entire length of the greenhouse. However, the direction of the wind tends to be important because the effectiveness of windows varies if they are windward or leeward (Molina-Aiz, 2010).

Figura 40. Transmissivity rates of various types of greenhouses oriented east-west and north-south in December and June



Source: Nisen (1969).

Type and dimensions

Greenhouse type and roof shape mainly influence the capture of solar energy (Von Elsner *et al.*, 2000a). A suitable roof slope (over 25 %) is necessary in Mediterranean greenhouses to prevent water condensation and dripping on plants (Von Zabeltitz, 1992).

One of the most important geometrical characteristics of a greenhouse is its width because this directly affects the airflow and ventilation ability, which can be directly determined by the distance between the windward and leeward side vents. Widths greater than 30 m are thus not recommended (Molina-Aiz, 2010); however, the majority of the greenhouses in Almería have widths greater than 30 m.

Height is an important consideration when designing greenhouses because it determines the unit volume. A greater greenhouse volume increases the response time of the indoor environment to changes in external weather conditions; therefore, higher greenhouses produce smaller fluctuations in the internal microclimate. Heights from 3.5 to 4 m to the ridge and 2.5 to 3 m as a minimum height for the cover and bands are recommended in order to enable the air movement over plants and to obtain good thermal inertia and reduce extreme temperatures (Valera *et al.*, 2002b).

High greenhouses offer important advantages, including high-efficiency ventilation. The greater height of the greenhouse increases pressure differences along the cover for high wind speeds, whereas it also improves ventilation by the chimney effect induced by a greater distance between the side and roof openings for low wind speeds (Von Elsner *et al.*, 2000a). In addition, higher greenhouses allow more space for the installation of climate control systems, such as thermal screens or shade screens, misting equipment, artificial lighting, etc. Thus, the current trend in greenhouse technology is towards higher greenhouses.

However, higher greenhouses increase energy consumption and place greater demands on structural stability because of the higher wind loads that must be supported. Therefore, the height of a greenhouse must be optimised with respect to these opposing factors.

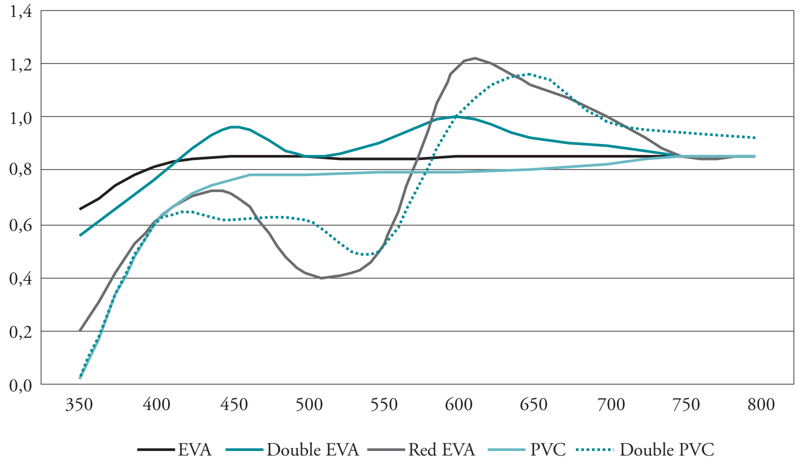
2.5.7. Cover materials

Another very important factor in the microclimate of the greenhouse is the cover material. The type of plastic used determines interior luminosity, heat loss due to infrared radiation, convection-conduction, and interior condensation. The following are characteristics of a good material for use as a single or double greenhouse wall that is temporarily or permanently installed (Nisen *et al.*, 1988):

- It must be cost effective, although it does not have to present the lowest purchase price.
- Its durability must be consistent with the lifetime guaranteed by the seller.
- It must provide maximum transmission to solar radiation, especially to visible or Photosynthetically Active Radiation (PAR).
- It must possess minimum transparency to Far Infrared Radiation (FIR), which is the energy radiated by the soil and plants that have absorbed incident solar radiation.
- It must be thermo-isolating, meaning that it must have the lowest possible heat-loss coefficient.

- It must not retain dust, which can rapidly reduce its transparency with regard to sunlight.
- It must produce moisture condensation in the form of a thin sheet of water, thus preventing the formation of large drops that can cause damage if they fall on the crop.

Figure 41. Transmissivity rates according to wavelength of different cover materials. In nm



Source: Nisen y Coutisse (1981).

The use of double-walled plastic increases minimum winter temperatures but limits the transmission of light (Nisen and Coutisse, 1981). Therefore, such material should be mobile and capable of being withdrawn during daylight hours, which is standard with sophisticated thermal screens (Albadalejo, 1991).

Flexible films

Flexible sheets are the most commonly used enclosure in countries along the Mediterranean basin, although their use is limited in colder countries of central and northern Europe (Table 2). Numerous flexible plastic films are available as greenhouse covers, including low density PE supplemented with stabilising additives called *Hindered Amide Light Stabilisers* (HALS) to improve certain properties, such as thermal effect, durability, photoselectivity, ultraviolet (UV) light stability, etc.; ethylene copolymers and vinyl acetate; coextruded films; plasticised polyvinyl chloride (PVC) (assembled or unassembled); polypropylene (PP); and permeable high density PE screens.

The use of plastics, along with sand plots, has undoubtedly been the determining factor for the greenhouse development in the province of Almería. Initially, greenhouses used PE plastic without any additives. However, other types of PE films have now become available, and farmers have incorporated these products into their greenhouses. The short life span of this type of cover, which is three years or less, has been instrumental in the rapid development of new materials.

Long-lasting 720 gauge (0.18 mm) PE is still used in many greenhouses because of its low cost (0.5-0.9 €/m^2) and an operational lifespan of two seasons. Thermal 800 gauge (0.2 mm) PE is also used because its operational lifespan can be as long three seasons and its cost is approximately 0.6-1 €/m^2.

Recently, coextruded film in three layers of PE and ethylene-vinyl acetate (EVA) in amounts that vary from 4 % to 14 % have appeared on the market and are spreading rapidly. However, 800-gauge films are the most accepted by farmers because of their operational lifespan, which is three growing seasons.

Fluorescent plastics can increase Photosynthetically Active Radiation (PAR) by changing the spectral composition of light (Castilla, 1994). The use of white plastic sheets on the ground to reflect radiation towards the interior of the foliage (Garzoli, 1989) and the use of reflectors or refractors (Jaffrin and Urban, 1990) have been suggested as methods of increasing the available radiation. Attention must be paid to the uniformity of radiation inside the greenhouse, especially in structures oriented E-W with a limited roof slope (Castilla, 1994).

New developments have also been made in «intelligent» plastics, such as those that hinder the orientation of insects inside the greenhouse or reduce the proliferation of fungi.

Table 2. Percentages of plastic-covered greenhouses in the European Union

Countries of the EEC	Plastic cover (%)
Spain	99
Italy	91
Holland	2
France	70
Portugal	98
Germany (West)	10
Greece	95
United Kingdom	15
Belgium	5
Denmark	2
Switzerland	14
Austria	20
Total	**74**

Source: Meneses y Monteiro (1993); PlastEuroFilm (1994); Horticultural Statistics (1994); Castilla y Hernández (1995); Scarascia-Mugnozza (1995); Briassoulis *et al.* (1997); CEPLA (1992); Von Elsner *et al.* (2000b).

Figure 42. Multi-span greenhouse with polyethylene cover and sides

Rigid plastics

There are several types of plastics that are marketed as rigid or semi-rigid panels that can be used as coating material, including glass-fiber reinforced polyester (GRP), rigid (not soft), polyvinil chloride (PVC), polymethyl methacrylate (PMMA) and polycarbonate (PC).

Many of the multi-span greenhouses built in the province have adopted PC corrugated sidewalls as lateral enclosures, and in some nurseries, they are used over the entire roof. Despite the high price (between 4 and 8 €/m^2 depending on the thickness) compared with that of flexible films, PC is an interesting product because it can last 10-12 years.

Also frequently used are cellular PC doors, which are priced from 7-9 €/ m^2 for panels 6 mm thick.

Figure 43. Multi-span greenhouse with a polycarbonate coated front

Horticultural glass

Horticultural glass is widely used for the construction of greenhouses in countries with cold climates. Glass as a cover material in the climatic conditions of Almería is not popular because of its high cost, between 8 and 12 €/m^2, compared with that of plastic. However, glass does provide greater insulation and lower costs of renovation because it provides a longer operational lifespan.

Tabea 3. Absorption (α), emissivity (ε), transmissivity (τ) and reflectivity (δ) for different types of radiation; heat loss coefficient (*U*) and density (ρ_c) of materials commonly used as greenhouse covers

Materials used in simple covers, double walls or as thermal screens	Thickness [mm]	Solar radiation (300-2.500 nm)			Visible radiation (380-760 nm)			Thermal radiation (2500-40000 nm)			U [W/m^2 ºC]	ρ_χ [g/cm^3]
		α = ε	τ	δ	α = ε	τ	δ	α = ε	τ	δ		
Horticultural Glass (HG)[b, d]	4	0.03	0.89	0.08	0.01	0.91	0.08	0.90	0.00	0.10	6.7	2.40
Reinforced Polyester Fiberglass (RPF)[g, f]	1	0.01-0.02	0.89-0.92	0.07-0.09	0.01	0.93	0.06	0.64-0.69	0.27-0.32	0.04		1.50
Rigid PVC[g, f]	18	0.11	0.62	0.27	0.02	0.61	0.37	0.92	0.01	0.07	3.8	1.30
Polymethyl methacrylate (PMMA)[g, f]	8	0.06	0.82	0.12	0.01	0.92	0.07	0.98	0.00	0.02	3.4	1.19
Polycarbonate (PC)[g, f]	4	0.08-0.11	0.78	0.14-0.15	0.06-0.10	0.75-0.79	0.15	0.89-0.98	0.02-0.03	0.09	3.5	0.17-0.20
Polyethylene without additives (PE)[d, g, f]	0.1	0.01	0.88-0.91	0.08-0.11	0.01	0.88-0.91	0.08-0.11	0.04-0.19	0.79-0.84	0.02	9.1	0.92
Low density polyethylene (PEld)[a, b, g]	0.18	0.03	0.88	0.09	0.01	0.89	0.10	0.13-0.40	0.53-0.80	0.07	9.4-16.2	0.91
Long lasting polyethylene (PEll)[g, b]	0.1	0.03	0.88	0.09	0.01	0.89	0.10	0.20-0.40	0.53-0.76	0.04-0.07	9.4-16.2	0.92
Infrared polyethylene (PEir)[h, d]	0.1	0.03	0.89	0.08	0.01	0.89	0.10	0.77	0.20	0.03	8.6-13.0	0.92
Thermal polyethylene (PEt)[a, d]	0.18	0.03	0.89	0.08	0.02	0.90	0.08	0.80	0.10	0.03	8.6-13.0	0.92
EVA Copolymers[g, f]	0.1	0.02	0.89-0.91	0.07-0.09	0.00	0.90-0.92	0.08-0.10	0.42-0.58	0.39-0.55	0.03	7.8	0.94
PE-EVA-PE Coextrusions[b, f, c]	0.2	0.02-0.04	0.82-0.89	0.09-0.14	0.01	0.82-0.85	0.14-0.17	0.59	0.38	0.03	8.8-10.4	0.93
Plasticised PVC[e, g, f]	0.1	0.02	0.91	0.07	0.01	0.92	0.07	0.62	0.06	0.32	7.7	1.30
Reinforced PVC[d, g, f]	0.15	0.06	0.73-0.74	0.20-0.21	0.03	0.73-0.76	0.21-0.25	0.53-0.76	0.09-0.32	0.15	6.5	1.30
Polypropylene (PP)[a, g]	0.8	0.06	0.74	0.20	0.04	0.73	0.23	0.69-0.71	0.21-0.26	0.05-0.08	11.2	0.91
HG+HG[g, f]	4+4	0.15	0.72	0.13	0.03	0.82	0.15	0.83	0.00	0.17	3.2	
HG+PE[g, f]	3.4+0.1	0.04	0.84	0.12	0.01	0.86	0.13	0.87	0.01	0.12	4.2	
HG+EVA[g, f]	3.4+0.1	0.04	0.84	0.12	0.02	0.86	0.12	0.87	0.01	0.12	4.0	
PE+PE[g, f]	0.1+0.1	0.03	0.83	0.14	0.00	0.84	0.16	0.28	0.66	0.06	6.8	
PE+EVA[g, b]	0.1+0.1	0.03	0.87	0.10	0.00	0.88	0.12	0.59-0.70	0.27-0.38	0.03	9.4-10.2	
Aluminised screen on both faces[a]	0.04							0.50	0.10	0.40	7.6	
Aluminised face towards the ground[a]	0.03							0.45	0.23	0.32	7.9	
Aluminised face towards the sky[a]	0.03							0.50	0.23	0.27	8.1	

Sources: [a]Feuilloley *et al.* (1989); [b]Feuilloley *et al.* (1994a); [c]Feuilloley y Issanchou (1996); [d]Nijskens *et al.* (1989); [e]Nijskens *et al.* (1984a); [f]Nijskens *et al.* (1984b); [g]Nisen y Coutisse (1981); [h]Nisen *et al.* (1984).

Figure 44. ***Venlo*****-type greenhouse in Almería**

2.6. Natural ventilation systems used in the greenhouse agriculture of Almería

The success of the typical Almería greenhouse is partly based on its simple and low-cost design; however, it is not the most efficient with regard to ventilation. The reduced ventilation causes high indoor humidity and results in condensation and dripping from the inside cover, favouring attacks by fungal diseases, which have traditionally required the application of phytosanitary products. The reduction of pesticide use is essential for both environmental reasons and the competitiveness of our products. For this reason, it is essential to improve ventilation in Almería greenhouses.

Natural ventilation causes significant climatic variability within the greenhouses and significant differences in relative humidity between areas close to the windows and areas far from them (Arellano *et al.*, 2002). In addition, an important temperature gradient occurs from the well cooled side vents openings to the centre of the greenhouse, in which excessive temperatures that can be higher than the outside temperature by 10 ^{0}C can be reached (Molina-Aiz *et al.*, 2003). The impact of ambient heterogeneity in production is important; in fact, a 3.1 ^{0}C lower average temperature and a 16 % higher relative humidity in the northern section of an Almería-type greenhouse with respect to the rest of the greenhouse can cause a 40 % loss of fruit yield (Arellano *et al.*, 2003).

These climatic deficiencies are associated with insufficient ventilation surface and the use of insect-proof screens in vents openings, which dramatically reduce the air-renewal rate but are used by almost all farmers in the region (Molina-Aiz, 2010). The main routes of technological improvement should rely on the natural advantages of the province of Almería on which the success of local greenhouse crops is based. These advantages are a climate with a very low risk of frost, less than once a year; a thermal swing of 13-14 ^{0}C annually; more than 3,000 sunshine hours per year; and steady winds during most of the year.

Investments in improvements to natural ventilation have occurred in recent years, although fewer improvements have been implemented with regard to shading meshes, extractor-based forced ventilation systems, and fog systems. However, some of these climate control systems imported from other climate zones with very different meteorological, market-related and socio-economic conditions from those of Almería have been proofed to be inefficient or barely effective, primarily because they have not been adapted to the specific needs of the horticulture in Almería.

It is worth emphasising that the main way of improvement in the climatic conditions in the traditional greenhouses in Almería, which are the overwhelming majority of the agricultural holdings, relies on further improving the natural ventilation systems. However, due to important economic interests and strong marketing pressures, some systems that have shown high efficiency in other climate and growing conditions have been introduced too quickly before the necessary studies could be performed to ensure their smooth operation and profitability in Almería.

Natural ventilation is a process that strongly contributes to the heat and mass transfer between the inside and outside environments. Therefore, a good design of those greenhouse characteristics that influence ventilation can improve climate control and energy efficiency. A greenhouse design that enables a modulation of the ventilation rate will maintain good control of the air exchange with the outside environment, thus improving the greenhouse microclimate and reducing the use of chemicals for crop protection.

In addition, ventilation determines the effectiveness of climate control equipment used in greenhouses, such as heating systems, energy-saving systems (thermal screens or double glazing), water-evaporation cooling systems (fog systems and fan-and-pad cooling systems) or CO_2-injection systems. Unfortunately, much of the available information detailing the effect of these parameters on indoor climate and production is from experimental studies often based on empty and small greenhouses, isolated modules and scale models.

2.6.1. Sidewall ventilation systems

Sidewall vent openings are found in 100 % of the Almería-type greenhouses and increasingly found in multi-span greenhouses, whereas in the *Venlo* type, they are only windows installed in the roof. The main types of lateral side vents are as follows:

Sliding sidewalls

Sliding sidewalls openings are most often used in the Almería-type greenhouses because they were initially adopted by the flat-type structures. This type of window consists of leaving the top edge of the plastic sheets located on the sides of the greenhouse, so it can slide between the two wire grids that constitute the perimetral enclosure.

Initially, wires were attached at the edge of the plastic and were used to hook the plastic to the different horizontal grid wires. This allowed the position of the plastic to be changed, thus obtaining different ventilation openings suface. Ropes are currently used, and they are attached to the top edge of the plastic and pass through pulleys located along the upper side walls, which facilitates the raising and lowering of the plastic (Figure 45). This type of opening is the most economical, and the incorporation of any other ventilation system implies an additional cost.

However, it takes a long time to raise or lower the plastic, as a large number of ropes must be used. In addition, when the opening surface is small, the irregular or curved form adopted by the plastic produces differences in air entry throughout the greenhouse, which allows water to infiltrate the greenhouse.

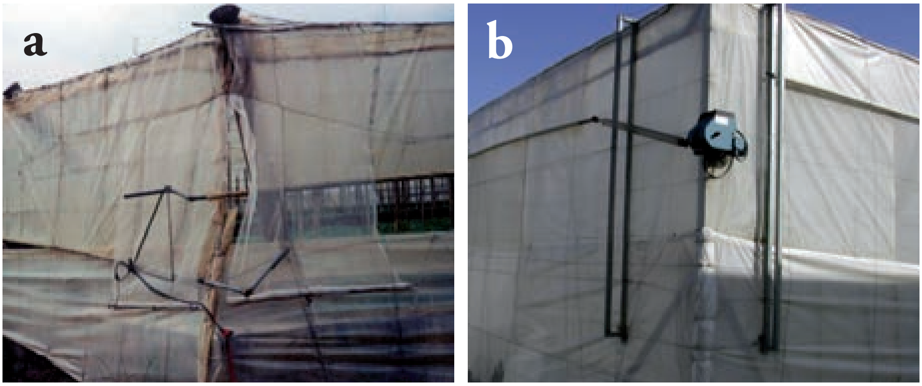
Figura 45. Sliding sidewalls with rope and pulley system

Roll-up openings with crank

This system implies attaching the plastic that covers the ventilation opening along the upper edge to the structure perimeter. The bottom edge of the plastic sheet is rolled up several times around a galvanised iron pipe (½ inch in diameter) and is attached to the pipe with wire twist-ties.

To open the window, the plastic pipe is rolled by means of a crank located at one of the ends (Figure 46a), and to close it, the plastic is unrolled. Since the crank is linked to the pipe, it is raised or lowered as the window is opened or closed at the same time that it is rolled up or unrolled in the pipe. The opening and closing system can also be automated by attaching gear motors to the pipes instead of the crank (Figure 46b).

Figure 46. Roll-up side openings with manual (a) and (b) motor-driven systems



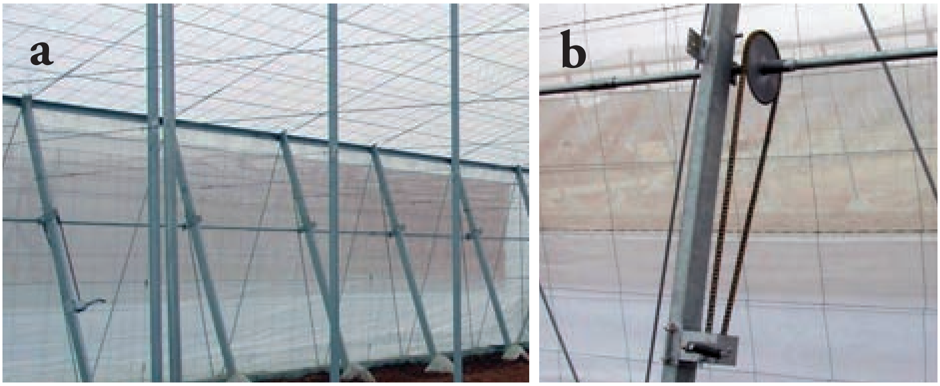
Sliding vents in Almería-type greenhouses

These vents are powered by a crank and opened downwards, sliding between the two wire grids.

In these openings, the plastic sheet is attached to the base of the greenhouse structure by its bottom edge, and the upper part is attached to a pipe of galvanised iron. A steel cable that passes by a small pulley at the upper part of the structure is attached to this pipe. The cable is rolled onto a second iron pipe and is then passed through another pulley located on the floor to attach the cable to the pipe holding the plastic (Figure 47).

The pipe on which the cable coils has a crank at the end and goes through small metal plates attached to the perimeter pillars, which serve as support. This system allows the crank to be turned so that the cable rolls up one way and unrolls the other, with one of the ends of the cable pulling the pipe located at the edge of the sliding plastic in the same direction that the cable is moving.

Figure 47. Sliding vent in an Almería-type greenhouse (a) and detail of manual system (b)



Roll-up windows in multi-span greenhouses

Although multi-span greenhouses traditionally did not incorporate side windows, this trend has been reversed (Figure 48).

Figure 48. Roll-up side windows in multi-span greenhouses

In these windows, the top of a strip of plastic (1-1.5 m in width) is attached to the top of the structure, and the bottom of the strip is attached to a circular pipe, which is powered by a tubular motor at its end. By turning the pipe, the plastic rolls to open the window or unrolls to close the window.

2.6.2. Roof ventilation systems

The roof ventilation systems used in greenhouses depend heavily on the structure type. Although the surface of *Venlo* and multi-span greenhouses is small in the province of Almería, most of the available data in the literature on ventilation tests correspond to these types of structures. Therefore, the roof ventilation systems incorporated in the *Venlo* and multi-span greenhouses, which provide greater benefits and normally have automated opening and closing by means of geared motors, will be presented along with the roof windows of Almería-type greenhouses below.

Although the oldest Almería greenhouses only have lateral openings, in recent years, there has been a massive incorporation of roof ventilation systems. Most of the greenhouses that do not have roof windows belong to the flat-top subtype structures. Virtually all the greenhouses that are built today feature this type of vents, which is indispensable in warm areas, such as the Mediterranean region. Most of the farmers have opted for flap roof windows because they have a rack and pinion system that allows for easy control of the opening surface and can be operated automatically through geared motors.

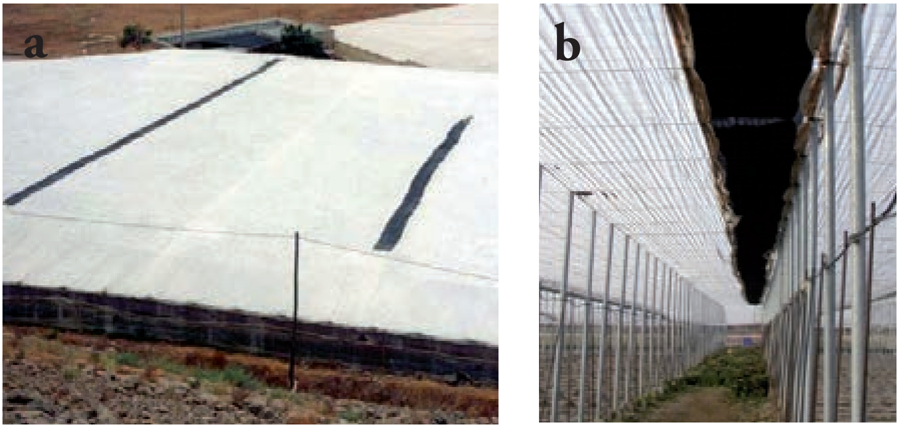
Sliding roof ventilation in Almería-type greenhouses

In the flat-top subtype, roof ventilation is usually performed through a hole (0.5-1 m wide) where the plastic cover is replaced by an insect-proof screen (Figure 49a).

Thus, an almost permanent ventilation opening is obtained because the vent opening operation is practically null, as it can only be closed by sliding the of plastic between the two wire grids that constitute part of the structure. To avoid problems caused by rainwater falling on the crop, the opening is placed over a service corridor.

In the ‘raspa y amagado’ subtypes, this type of opening is usually located on the leeward side of the ridge slope (Figure 49b). Although there is still a significant percentage of greenhouses using this system, its replacement by other types of more efficient windows is expected in the coming years.

Figure 49. Roof ventilation openings of Almería greenhouses: a) exterior view of the flat-top subtype and b) interior view of the 'raspa y amagado' subtype

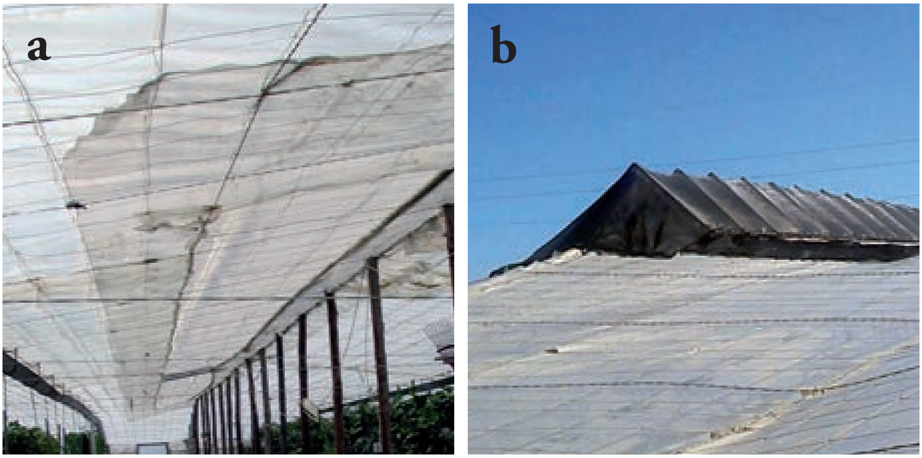


Rolling roof windows in Almería-type greenhouses

An improvement of the previous ventilation system is the utilization of a roll-up opening in which the free end of the plastic ventilation opening is rolled up around a cylindrical pipe that rotates in one direction or another according to whether it is being opened or closed.

However, this type of opening is difficult to power when it is very long, as it produces deficiencies in closing because of variations in the tension of the plastic, which misaligns the pipe around which the flexible sheet is wound (Figure 50a).

Figure 50. Roll-up roof (a) and pyramidal openings (b) located on the ridge of the Almería-type greenhouse



Pyramidal roof openings in Almería-type greenhouses

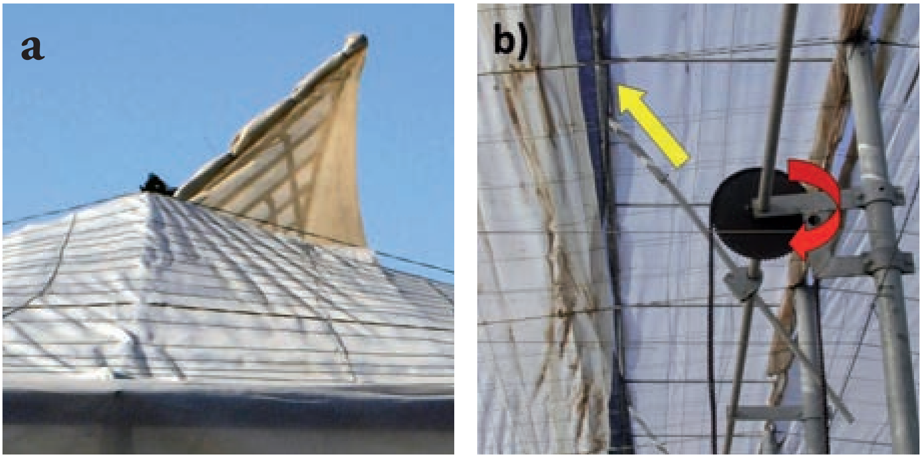
A particular type of roof window that can be used in the flat-top and ‘raspa y amagado’-type greenhouse is the pyramidal opening (Figure 50b), which is composed of two roll-up openings that are placed on either sides of the ridge and move on a metallic triangular structure. These windows have the advantage of being able to open up to the windward or leeward side as needed, although they produce increased shading, pose a greater burden on the structure, and are more expensive than the other previously mentioned types.

Flap roof vents in Almería-type greenhouses

Most of the ‘raspa y amagado’ greenhouses built today are being equipped with small roof windows placed on the ridge along the length of the greenhouse. These windows consist of a small metallic structure attached to the wire mesh of the greenhouse structure by means of a rotating axis and slide bearing plates of the control rods, which control the openings using a rack and pinion system. The plastic is attached to the opening frame using a small auxiliary wire mesh.

This type of window has been installed in many greenhouses with further structural improvements because of their low cost, between € 2 and 3 per linear metre of window.

Figure 51. Roof flap vent in a 'raspa y amagado' greenhouse (a) and detail of the rack and pinion system that allows manual or motorised operation (b)



Roof windows in multi-span greenhouses

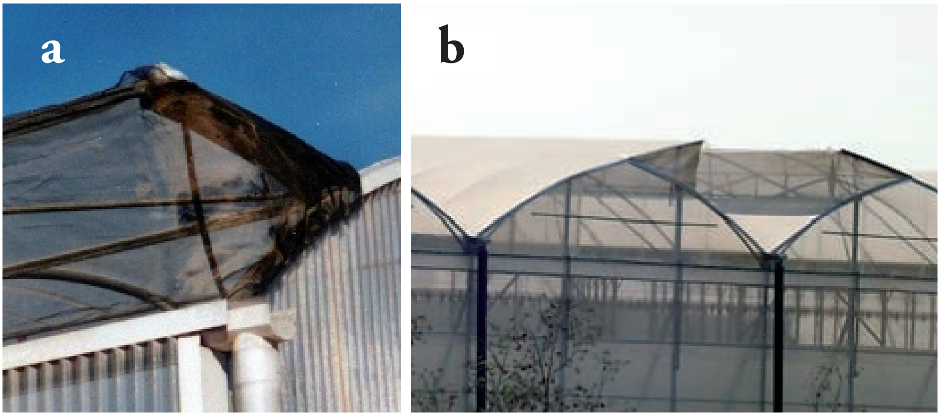
These greenhouses are often equipped with long windows (up to 100 m) that consist of roof parts that open towards the outside. In early designs, the roof windows constituted half of the roof that turn around the ridge axis and closed over the gutters, which is why they are called «half arch' windows (Figure 52).

In other cases, smaller windows are used, and they only occupy a small part of the roof (approximately ¼) (Figure 53a). The closure is also performed over the gutter that separates the different modules of the greenhouse. Another alternative is to use «medium arch» windows by moving the closure area to ¼ from the arch (Figure 54a) because these windows can improve the evacuation of heat that accumulates in the upper part of the cover. The two types of windows are opened through a rack and pinion device that rises or descends by rotating around an axis driven directly by electric motors.

Figure 52. «Half arch» roof windows over the gutter of a multi-span greenhouse

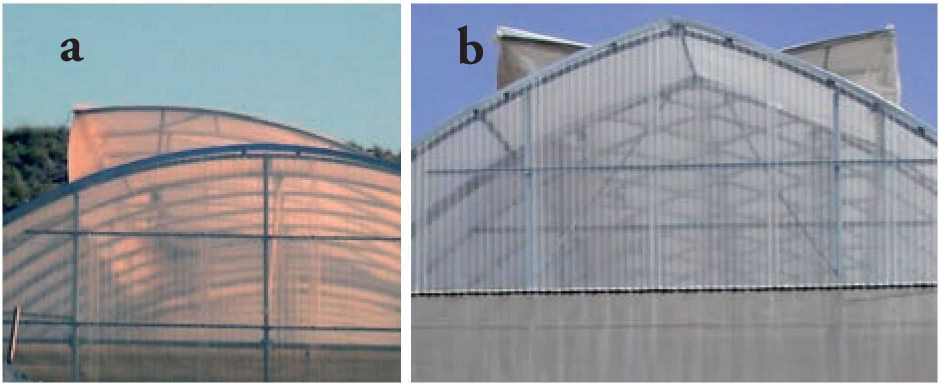
So-called «superzenith» windows (Figure 53b) allow the vent opening to be located in the centre of the ridge at a greater height to improve the effectiveness of ventilation closer to the ridge and prevent the entry of insects that are vectors of viral diseases, which usually fly at lower altitudes. This type of window is closed through a longitudinal «omega» belt with plastic fastenings. A drawback of this system is that it makes it difficult to form a tight seal that prevents the entry of rainwater that slides along the greenhouse cover.

Figure 53. Roof windows of multi-span greenhouses: at ¼ (a) and «superzenith» (b)



In the Almería area, the opening of roof windows depends on the wind speed: winds higher than 4-5 m s^{-1} reduce the degree of opening by 80-90 %. Windows are closed with wind speeds of 10-15 m s^{-1} or more, leaving a small opening of 1-2 % to avoid over-pressurisation from a sudden input of air in the greenhouse.

Figure 54. Roof windows of multi-span greenhouses: ½ arch moved towards the centre of the arch (a) and butterfly type (b)



Roof windows in *Venlo*-type greenhouses

Roof ventilation is usually conducted through small windows consisting of 1 to 3 glass panes that have widths of 82, 100 or 120 cm and that rotate around an axis located in the ridge.

The maximum angle of opening in this type of window is 44º (Von Elsner *et al.*, 2000 b). The window opening and closing system can be drive on a swing mechanism or on a truss rail mechanism. In the last system the manin rail is placed above the cross truss that constitute the structure. The latter system has been used in greenhouses built in Almería, as it has the advantage that the elements that compose the structure do not increase the shade over the crops (Figure 56).

Normally, openings are placed discontinuously by alternating on either side of the roof, although certain glass greenhouses in Almería have roof windows installed along the entire length of the greenhouse to increase the surface of ventilation.

Figure 55. Alternate windows in a *Venlo* greenhouse constructed in Almería

Figure 56. Interior view of discontinuous windows in a *Venlo* greenhouse

2.6.3. Efficiency of natural ventilation

In Mediterranean greenhouses, the most important factors in climate control are the ventilation surface area and the type of openings used for ventilation (Wacquant, 2000). The openings for ventilation are essential functional elements of a greenhouse, and their location and design can strongly influence the quality of the indoor microclimate and the energy efficiency of the greenhouse. In most of the greenhouses in Almería, and in the Mediterranean region in general, the renewal of indoor air is accomplished exclusively by passive ventilation; thus, the design of ventilation openings should allow strategies for maintaining a high ventilation rate under different weather conditions (Von Elsner *et al.*, 2000a).

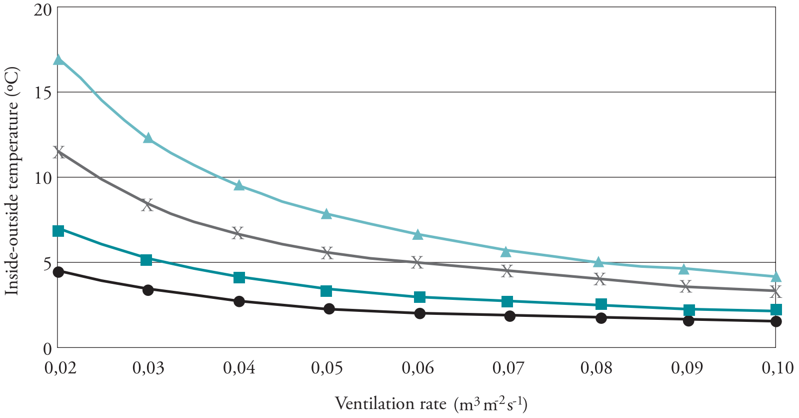
Ventilation surface

For optimal crop growth, sufficient ventilation must be supplied, especially when the outside temperature is high, global radiation is high and the interior humidity of the greenhouse is high. In addition, ventilation is especially important for multi-modular greenhouses (FAO, 2002), which is characteristic of the 'raspa y amagado' greenhouses.

The ventilation rate required to maintain a certain temperature difference between the inside and outside of the greenhouse can be calculated by means of energy balances. Figure 23 shows the relationship between the evapotranspiration rate of the crop inside the greenhouse, the temperature gradient and the ventilation rate of a greenhouse with a plastic cover (transmissivity of covering, $\tau = 0{,}80$) for a global solar radiation value of 700 W m^{-2}. The effect of ventilation on the temperature of the greenhouse is not linear, and beyond a certain ventilation rate (0.1 m^3 s^{-1} m^{-2}), the temperature effect is limited (Seginer, 1997), as shown in Figure 57.

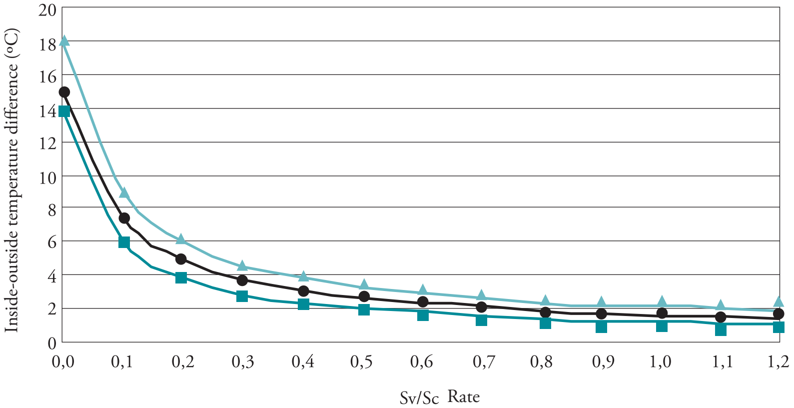
The ventilating capacity in a greenhouse and therefore the ability to reduce the temperature gradient in relation to the outside depends on the size of the window openings. Figure 58 shows the maximum ventilation surface as a percentage of covered ground surface.

Figure 57. Temperature differences between the inside and outside of a greenhouse according to ventilation rate for four crop evapotranspiration levels (L_{ETP}). Expressed as a percentage of net radiation inside the greenhouse (*Rn*): 20 % (●), 50 % (♦), 70 % (■) y 80 % (▲)



Source: adaptaded from FAO (2002) and ASAE (2003).

Figure 58. Temperature differences between the inside and outside of a greenhouse as a function of the relationship between the ventilation surface (S_V) and covered ground surface (S_c), for a null wind speed in a greenhouse with roof and side openings and values of outside solar radiation of: 1000 W m^{-2} (■), 750 W m^{-2} (♦) y 500 W m^{-2} (▲)



Source: adaptaded of Kittas *et al.* (1997).

However, opening size is not the only design parameter that influences the effectiveness of the ventilation of a greenhouse. The position, shape and operation of the ventilation openings also strongly influence the rate of air renovation rate in the greenhouses.

Pressure distribution generated by external wind on the greenhouse cover induces a flow of air inside the greenhouse when there is a pressure difference among the open windows (Wacquant, 2000). Pressure differences depend on the shape of the cover and placement of the windows. Therefore, the position of the ventilation openings is an extremely important factor for obtaining a strong pressure gradient along the length of the interior of the greenhouse, which ensures good ventilation (Von Elsner *et al.*, 2000a).

It has been observed that roof openings usually induce a higher ventilation rate when only the air exchange generated by wind is considered (Papadakis *et al.*, 1996). The main reason for this effect is that side openings are usually located along the lower part of the walls at approximately 1 m above the ground. At this height, the wind speed is strongly reduced by friction with the ground. In addition, the effects of aerodynamic pressure differences induced by the shape of the cover are stronger at the roof openings. However, side openings are necessary to induce ventilation generated by the thermal buoyancy of hot air when the wind speed is low because it has been observed that roof windows by themselves cannot create an effective ventilation flow in low-wind conditions (Mistriotis *et al.*, 1997b). However, side openings are considered secondary in various greenhouse designs, particularly in northern Europe, where there is a reduced need for ventilation. Thus, large numbers of multi-span or *Venlo*-type greenhouses from colder geographic areas are built in Almería without side openings, constituting a serious design flaw.

Verheye and Verlodt (1990) observed that ventilation reached its optimum value for a total opening surface of approximately 30 % of the growing surface. Von Zabeltitz (1992) recommended window surfaces of 18-25 % relative to that of the growing surface to improve the passive ventilation in the Mediterranean area, and the ASAE (1994) reduced this limit to a minimum of 15 %. Feuilloley *et al.* (1994b) indicated that the surface of side ventilation must be between 17 % and 15 % of the roof windows in multi-span greenhouses. Giacomelli (2002) recommended that the rate between ventilation surface and ground surface covered by the greenhouse should be between 10 and 20 % for regions with high solar radiation. According to the Food and Agriculture Organization of the United Nations (FAO, 2002), the total surface of the ventilation openings must be between 15 and 25 % of the ground surface to provide sufficient ventilation. In greenhouses with insect-proof screens in the ventilation openings, these percentages should be increased to offset the resulting decrease in airflow.

Vent openings configuration

To produce natural ventilation a pressure difference between the outside and inside air must be generated; this pressure difference can be created by the effect of wind or by a thermal gradient. The best method for achieving such a pressure difference is to place ventilation openings on both side walls and along the ridges of the greenhouse (FAO, 2002).

In greenhouses, the crop lines should be placed parallel to the direction of the prevailing winds to increase the number of air changes per hour (FAO, 2002). The presence of crops situated in lines perpendicular to the openings can cause decreases of ventilation flow of up to 28 % (Boulard *et al.*, 1997).

In the case of individual or multi-modular greenhouses with side ventilation, the maximum air change rate is achieved when openings are located perpendicular to the predominant wind direction, whereas in the case of grouped multicellular structures with spaces between two structures, the sides must be parallel to the direction of the wind. If ventilation is achieved only through the sides, the maximum width of the greenhouse should be limited (FAO, 2002).

Vent openings design is an important factor in the efficiency of ventilation, with the continuous type used in multi-span greenhouses being more effective than the discontinuous design used in *Venlo*-type greenhouses (Boulard *et al.*, 1997). Greenhouses equipped with roof openings (Kittas *et al.*, 1996) or roof and lateral windows always provide more natural ventilation than those with only side ventilation (Papadakis *et al.*, 1996).

In the case of individual greenhouses, the surface of side ventilation must be equal to the surface of the roof windows. Roof windows have hinges on the top that allow for a continuous opening along the entire length of the greenhouse. When these windows are fully opened, they should form a 60° angle with the roof (FAO, 2002). Specifications for the design of the greenhouse ventilation vary according to the geographic location of the greenhouse.

If the climatic conditions require a high degree of ventilation efficiency, as in the case of Almería, then several basic window specifications must be considered (Von Elsner *et al.*, 2000a):

- A high rate of air renewal under the maximum range of meteorological conditions must be maintained. Greenhouses should be equipped with ventilation systems that allow air renewal through both wind effects and thermal buoyancy (thus making roof and lateral windows necessary).
- Windows must be designed to provide maximum airtightness when closed, thus preventing heat losses during cold nights.
- The window size must be compatible with the capacity of the structure and characteristics of the covering material, and the windows should not weaken the structural stability of the greenhouse.
- The ventilation mechanisms must not reduce light transmission through shading effects; thus, it is advisable to incorporate them into the already existing structure.
- The window design should ensure crop protection from direct rainfall, even when the windows are open.

Adequate ventilation levels

Ventilated airflow is directly related to the thermal gradient between the inside and outside of the greenhouse (Buffington *et al.*, 1987) as well as to variation in moisture. Ventilation requirements are variable and must conform to the growth and development requirements of crops and, most importantly, to outside climatic conditions. Thus, recommendations for required air renewal in greenhouses may vary from 2 h^{-1} (air renewals per hour) in winter up to 60 h^{-1} in summer (Buffington *et al.*, 1987).

According to Businger (1963), a minimum renewal value of 10 h^{-1} is required in summer under favourable lighting conditions, although renewal values of 50 to 100 h^{-1} are recommended. Similarly, the renewal values required to obtain a specific thermal jump according to the level of crop evapotranspiration vary between 35 and 90 h^{-1} (ASAE, 2003), with an optimum value of 45 to 60 h^{-1} (Hellickson and Walker, 1983; ASAE, 1994).

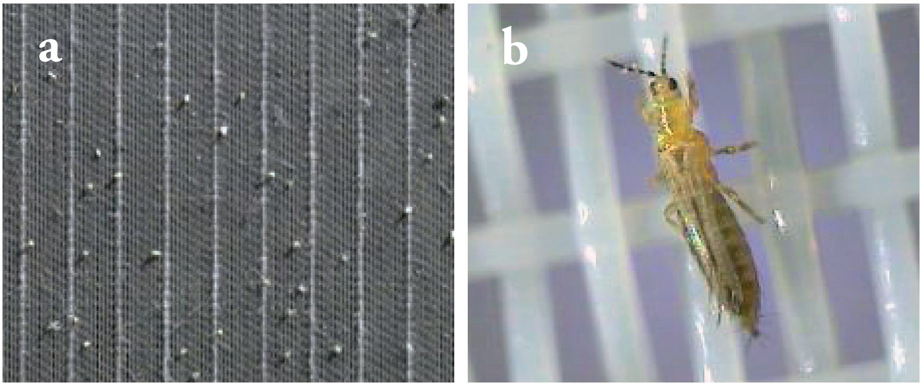
Air renewal values of 1.5 to 3.5 $m^3\ s^{-1}\ m^{-2}$ (airflow that passes through the window over the surface of the greenhouse) are also recommended and necessary to prevent condensation on the greenhouse cover because of increases in internal moisture (Buffington *et al.*, 1987). In the case of forced ventilation, a ventilation capacity of approximately 2.4 $m^3\ s^{-1}\ m^{-2}$ can be considered appropriate (Giacomelli, 2002).

2.6.4. Insect-proof screens used in greenhouse vent openings

Crop protection has become increasingly important. Although pesticides are still an important tool for pest control in greenhouses, their use is no longer favoured, and the adverse effects caused by chemicals products, including environmental pollution and insect resistance, has led to the search for alternative methods of crop protection. One of these alternatives consists of placing screens in greenhouses windows, which can prevent or reduce the entry of small insects (Figure 59), thereby reducing requirements for phytosanitary treatments. Another very successful alternative in Almería is biological control.

The use of mosquito screens in Almería greenhouses was initially intended to protect the crop from wind action (Camacho-Ferre, 1980). Currently, almost all vent opening are equiped with insect-proof screens as a preventive measure against the entrance of pest insects. In addition, Andalusian legislation for integrated production established that screens with a minimum density of 10 x 20 threads/cm^2 must be installed in the openings of the greenhouses of the Region (Order of 10 October 2007, Specific Rules of Integrated Production of Protected Horticultural Crops, BOJA Nº211 of 25 October 2007).

Figure 59. Whiteflies on the exterior face of an insect-proof screen placed in the window of a greenhouse in Almería (a). Enlarged image of thrips on a screen (b)

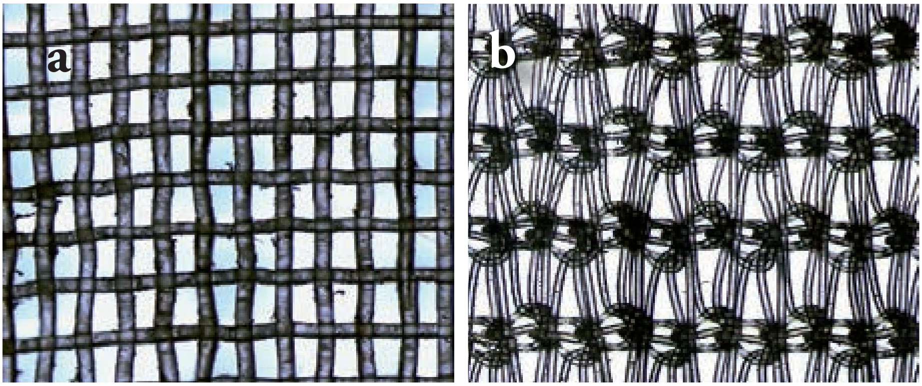


However, the installation of screens constitutes an obstacle to airflow, which leads to a reduction of the interior air speed and of the ventilation rate. Because of the decreased number of air renewals, both temperature and moisture increase, thus affecting the general microclimatic conditions in the greenhouse. Despite the drawbacks, insect-proof screens are a useful alternative in crop protection, and selecting the most suitable screen for a greenhouse requires understanding its effectiveness as a barrier against pests as well as its resistance to air flow.

There are two types of insect-proof screens used in greenhouses, which are differentiated according to their manufacture (Valera *et al.*, 2001):

- *Fabric.* This is currently the most common form of screen structure because they provide a good balance between the gap size required for the exclusion of insects and resistance to air flow. The main disadvantage is that if the holes are distorted, the application of side tension can negatively affect the exclusion of insects and the aerodynamic resistance. In general, the fabrics are woven with PE monofilament threads (Figure 60a), which means that each thread is composed of a single solid strand that is similar in appearance to fishing line. The filaments can also be composed of different acrylic fibres, which are known as multifilament yarns.
- *Knotted.* In this type of screens, each thread is tied around the next one, forming a knotted mesh (Figure 60b) that have high resistance to tearing and breaking. Additional ties and knots can significantly lower the permeability of the mesh.

Figure 60. Details of a woven (a) and knotted insect-proof screen (b)



Effectiveness of screens as a barrier against pests

Among the major pests that can be prevented by screens are whiteflies (*Trialeurodes vaporariorum* Westwood and *Bemisia tabaci* Gennadius), which produce yellowing and weakening of plants and the appearance of black spots as indirect damage, and thrips (*Frankliniella occidentalis* Pergande). These two insects constitute the most important pests of greenhouse crops in Almería (Acebedo, 2004). Similar to other locations in the world (Taylor *et al.*, 2001), the majority of losses in Spain caused by *B. tabaci* are related to their role as a vector for viruses (Guirao *et al.*, 1997). Tomato Yellow Leaf Curl Virus (TYLCV) was documented for the first time in Spain in the autumn of 1992 (Moriones *et al.*, 1993). Thrips also cause indirect damage by transmission of the Tomato Spotted Wilt Virus (TSWV), which can affect tomato, pepper, eggplant and bean fields (Aparicio *et al.*, 1998).

Other harmful insects whose entry to the greenhouse can be halted with insect-proof screen are aphids (*Myzus persicae* Sulzer and *Aphis gossypii* Glover), which are the most common and abundant pests on certain greenhouse vegetable crops, such as Solanaceae. In addition to causing direct damage to plants, these insects can transmit many viral diseases. The leafminer (*Liriomyza* sp.) also causes direct physical damage to the crop.

The resistance to insecticides has led to a decrease in the effectiveness of chemical protection in addition to the increasing environmental and economic disadvantages resulting from its use. In an integrated pest control system, the physical exclusion of insects should be one of the first techniques applied to reduce the need for other control measures (Bell and Baker, 2000). With the elimination or increase in cost of many registered pesticides, the use of insect-proof screens has become the most economically effective technique combined with biological control.

The use of insect-proof screens in the ventilation openings of the greenhouses has reduced pest populations, lowered the incidence of disease transmission and decreased the need for phytosanitary treatments (Berlinger *et al.*, 1991, 1992; Baker and Jones, 1989, 1990; Bell and Baker, 2000). The effectiveness of insect-proof screens as a barrier to insects has been studied by various authors (Albright and Both, 1990; Bethke and Paine, 1991; Bethke, 1994; Bethke *et al.*, 1994; Bell and Baker, 2000; Fernández *et al.*, 2002a-b; Ghidiu and Roberts, 2003; Díaz *et al.*, 2003). The smaller dimensions of thrips reduced the effectiveness of 10 × 16 threads/cm^2 screens; therefore, the use of denser screens (10 × 20 threads/cm^2) has expanded. This dense screen is equivalent to 50 mesh (1 mesh = 1 thread/inch) and tends to have a maximum hole diameter of 0.22-0.27 mm, which has great efficiency in the control of whiteflies (Díaz *et al.*, 2003). Densities of threads can be much higher (14 x 28 threads/cm^2, 13 x 30 threads/cm^2, etc.), reaching up to 20 × 40 threads/cm^2.

The effectiveness of screens as a physical barrier to the passage of insects depends on the minimum size of the pores or holes that compose the screen. Normally, screens are named according to the number of horizontal and vertical threads in 1 cm^2. This nomenclature is directly related to the size of the holes and porosity, although the relationship is not clear; therefore, depending on the thickness of the strands forming the fabric of the agro-textile material, identical values of porosity can be obtained with different numbers of threads per centimetre and different hole sizes. Table 10 presents the sizes of holes (both as surface and as maximum length) that can prevent the passage of various types of insect pests.

Table 4. Maximum size of mesh pores for the exclusion of various insect pests

Insect pest	Size of thorax (mm)[c]	Size of abdomen (mm)[c]	Maximum pore length (mm)[e]	Maximum pore surface (mm^2)
Thrips	0.213-0.215	0.265	0.192	0.03[a]
Whitefly	0.239-0.288	0.565-0.708	0.462	0.20[b]
Aphids*	0.355-0.434	2.295-2.394	0.340	0.20-0.90[d]
Leafminers	0.435-0.608	0.810-0.850	0.640	0.40[d]

**Although aphids are larger than whiteflies, a denser screen may be necessary because of the different placement of the wings with respect to the body.*

Source: adaptaded from [a]Albright and Both (1990); [b]Bethke and Paine (1991); [c]Bethke (1994); [d]Bethke *et al.* (1994); [e]Ghidiu and Roberts (2003).

The effectiveness of insect-proof screens has been studied in the laboratory by comparing the size and geometry of the pores with the width of the thorax of insects in the absence of forced airflow (Bethke and Paine, 1991). Trials have also been conducted in wind spans (Bell and Baker, 2000) to determine the effectiveness of different types of screens by counting caught-in insects (Table 5) while subject to an air current of 1.5 m s^{-1}, a value that approximates the flow rate of air through the lateral windows of greenhouses (Molina-Aiz *et al.*, 2004a-b).

Table 5. Effectiveness of different insect-proof screen types as barriers to insect pests

Screen type (threads/cm^2)	Thread thickness (mm)	Average hole size (mm)	Exclusion of whitefly (%)	Exclusion of thrips (%)
40 × 40	0.10	0.15 × 0.15	89.7* ± 2.1**	75.5 ± 11.8
32 × 32	0.17	0.14 × 0.14	86.8 ± 5.0	94.8 ± 3.5
20 × 32	0.16	0.15 × 0.34	92.7 ± 1.5	22.3 ± 14.6
20 × 20	0.16	0.35 × 0.35	93.9 ± 3.5	4.2 ± 15.0
16 × 16	0.20	0.43 × 0.43	71.5 ± 36.1	15.8 ± 13.7
12 × 12	0.22	0.65 × 0.65	12.5 ± 21.9	18.8 ± 13.9
10 × 20	0.26	0.26 × 0.81	73.1 ± 17.6	18.0 ± 14.6
10 × 16	0.27	0.41 × 0.79	14.2 ± 27.0	2.2 ± 12.9

* *Valores medios;* ** *Desviación estándar.*

Source: Adapted from Bell y Baker (2000).

Although this type of testing provides an index of the relative effectiveness of screens, it is not a particularly accurate method because larger gap sizes can lead to greater efficiency (Table 5). To determine the exact effectiveness of a screen as an insect barrier, the percentage of insects that manage to cross it in real field conditions must be known.

Certain screens include additive filaments with substances that impart a photo-selective character and have the capacity to absorb UV rays (between 230 and 380 µm), which disrupts the orientation of the many insects that rely on UV frequencies. Although laboratory studies have shown greater effectiveness as an insect barrier, in Almería greenhouses, significant differences compared to normal screens were not observed (Díaz *et al.*, 2003).

Screens of 10 × 20 threads/cm^2 installed in Almería greenhouses maintain low values (< 9 %) of plants infected with TYLCV (Fernández *et al.*, 2002a-b; Díaz *et al.*, 2003). However, screens do not ensure complete protection because Almería-type greenhouses are not completely airtight, as the plastic cover must be pierced to attach the screens to the structure. In addition, the lack of uniformity of the screens (Álvarez *et al.*, 2003) and the larger size of the actual holes in the three-dimensional configuration produce holes that are larger than the nominal size and through which insects can pass.

In addition, when the ridge of a greenhouse is oriented in an E-W direction and there is a larger surface of windows exposed to winds from the southwest, an increase in the incidence of spoon virus occurs because of the increased air renewal and insect entry (Fernández *et al.*, 2002 b; Díaz *et al.*, 2003).

Negative effect on ventilation

Insect-proof screens in the vent openings of the greenhouse produce a considerable negative effect on the rate of ventilation and therefore on the microclimate inside the greenhouse (Molina-Aiz, 2010). Screen resistance to air flow is reflected in pressure loss through the screen, which varies with the approximate velocity of air approaching the screen. It is recommended that the pressure drop through the screen does not exceed a static pressure of 7.35 Pa (Mears and Both, 2000).

The measurement of screen resistance to the passage of air is performed by trials in wind tunnels in which the pressure loss caused by the porous material for a given air speed can be determined (Miguel *et al.*, 1997). This approach has been used by various authors (Miguel, 1998a and 1998b; Dierickx, 1998; Muñoz *et al.*, 1999) and is based on the Forchheimer equation (Molina-Aiz, 2010), which establishes a relationship between the pressure drop caused by the screen, incoming air velocity and the square of the incoming air velocity. Bell and Baker (2001) also measured the pressure drop caused by various types of screens for an air velocity of 1.5 $m\ s^{-1}$ (Table 6).

Table 6. Porosity and resistance to air flow of different types of insect-proof screens

Screen type (threads/cm^2)	Porosity (m^2/m^2)	Permeability K_p (m^2)[a]	Inertial factor Y[a]	Pressure drop ΔP (Pa)[b]
40 × 40	0.36	6.71 × 10 –10	0.379	23.6
32 × 32	0.20	2.62 × 10 –10	1.325	65.5
20 × 32	0.31	5.28 × 10 –10	0.521	18.4
20 × 20	0.46	9.93 × 10 –10	0.225	12.1
16 × 16	0.47	1.03 × 10 –09	0.215	10.4
12 × 12	0.45	9.58 × 10 –10	0.236	5.4
10 × 20	0.40	6.51 × 10 –09	0.457	5.0
10 × 16	0.34	1.39 × 10 –09	0.758	5.9

Source: adapted from [a] Miguel (1998b); [b] Bell and Baker (2001).

Valera *et al.* (2006) and Molina-Aiz (2010) also studied the characteristics of different types of screens used in greenhouses through wind tunnel trials (Table 7).

Tabla 7. Porosity and resistance to air flow of different types of insect screens measured in a wind tunnel

Screen	Density (threads/cm^2)	Porosity α(m^2 m^{-2})	L_{px} (μm)	L_{py} (μm)	d_m (μm)	K_p (m^2)	Inertial factor Y	ΔP (Pa)*
Sunsaver	18 × 33	0.288	127.2	386.2	175.34	4.50 × 10–10	0.266	24.5
Sunsaver	11 × 23	0.319	194.9	711.7	251.76	1.33 × 10–9	0.186	13.8
UAL 2008-2	10 × 20	0.325	225.4	724.8	275.05	2.02 × 10–9	0.177	12.7
UAL 2007-1	10 × 20	0.335	233.7	734.0	274.90	2.12 × 10–9	0.169	11.6
Econet T	20 × 40	0.336	162.6	334.6	165.45	4.57 × 10–10	0.273	24.3
UAL cenital	10 × 20	0.341	233.0	741.3	271.96	2.60 × 10–9	0.253	8.9
UAL 2011-1	10 × 20	0.350	238.6	746.0	266.60	2.31 × 10–9	0.166	9.5
BioNet	10 × 20	0.367	245.5	804.9	258.37	2.17 × 10–9	0.157	8.8
Sunsaver	10 × 20	0.371	267.7	795.3	271.04	1.91 × 10–9	0.166	9.5
Sunsaver	10 × 20	0.375	247.3	777.4	253.20	1.88 × 10–9	0.163	8.5
UAL 2008-3	09 × 21	0.375	234.9	838.7	246.90	3.15 × 10–9	0.164	8.0
UAL 2008-1	10 × 20	0.379	256.6	736.4	250.25	2.69 × 10–9	0.179	7.0
UAL 2007-3	13 × 27	0.385	188.4	591.6	184.40	1.97 × 10–9	0.186	9.9
Supertex-30	10 × 20	0.387	256.5	839.9	251.21	1.97 × 10–9	0.164	8.4
Econet SF	10 × 20	0.389	263.7	775.0	252.55	1.70 × 10–9	0.155	8.3
UAL 2007-4	13 × 31	0.390	164.6	593.3	165.85	1.93 × 10–9	0.159	9.7
UAL 2008-4	13 × 31	0.390	164.6	593.3	165.85	1.93 × 10–9	0.159	9.7
UAL lateral	10 × 16	0.394	337.2	694.2	279.20	6.91 × 10–9	0.193	5.8
Supertex-26	10 × 16	0.458	415.6	748.8	260.68	2.65 × 10–9	0.151	5.3
UAL 2007-2	10 × 16	0.470	383.3	792.8	243.15	4.80 × 10–9	0.167	5.1
Sunsaver	10 × 16	0.477	379.1	771.5	244.66	5.06 × 10–9	0.197	4.1
Econet F	10 × 16	0.483	410.0	789.7	253.47	4.15 × 10–9	0.136	3.3

ΔP Presure drop.
K_p Permeability.
L_{px} Pore length on the x-axis.
L_{py} Pore length on the y-axis.
d_m Average thread diameter.

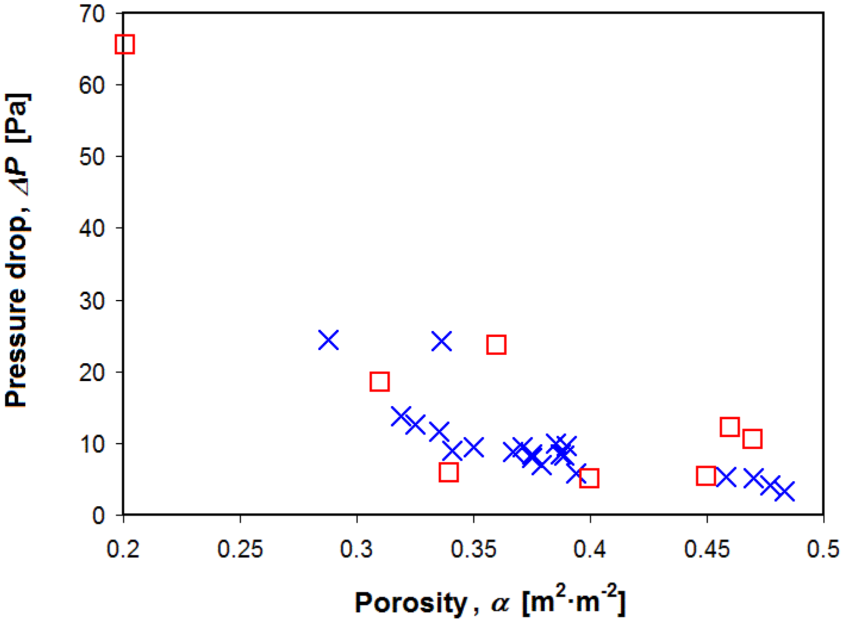
* *Pressure drop corresponding to the velocity of the passage of air of 1,5 m/s.*

Source: Valera *et al.* (2006); Molina-Aiz (2010).

From the results obtained by different authors, a relationship between porosity and the resulting pressure drop (Figure 61) can be observed, although the thickness and density of the threads must also be considered. Reducing the thickness of the thread can increase the porosity of the screen and reduce the size of the pores (Table 7).

Other authors have used a discharge coefficient to evaluate the influence of screens in the natural ventilation of greenhouses (Sase and Christianson, 1990; Kosmos *et al.*, 1993; Montero *et al.*, 1997; Teitel and Shlylar, 1998).

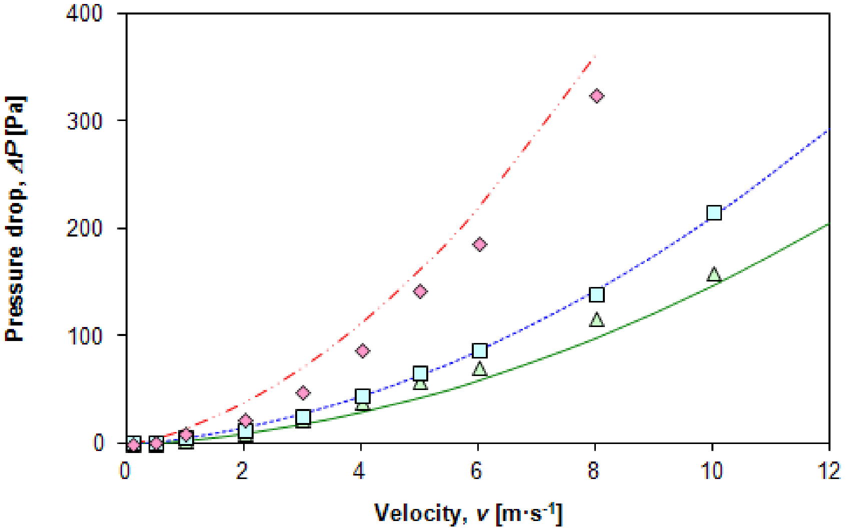
Figure 61. Relationship between screen porosity and pressure drop produced by the passage of air with a velocity of 1,5 m/s



Source: (■) Bell and Baker (2001) y (×) Valera *et al.* (2006) y Molina-Aiz (2010).

The measure of the screen resistance to the passage of air can be conducted experimentally by wind tunnel testing to obtain the pressure loss caused by the porous material for a given air speed (Miguel *et al.*, 1997; Valera *et al.*, 2006) or through computational fluid dynamics (CFD) simulations (Figure 62).

Figure 62. Pressure drop using three types of insect-proof screens as a function of air velocity: 10 × 16 [hilos/cm^2] (-----; Δ), 10 × 20 [hilos/cm^2] (- - -; □) y 15 × 30 [hilos/cm^2] (·-··-·; ◊)



Source: Experimental data obtained from Valera *et al.* (2006) and Álvarez (2009) and simulated data with CFD from Molina-Aiz (2010).

Molina-Aiz (2010) used CFD simulations of an Almería-type greenhouse and observed how the use of insect-proof screens strongly reduces the air speed inside the greenhouse (mostly within the crop area) and the ventilation rate, producing a significant increase of the internal temperature. Similar results have been obtained by various authors (Bartzanas *et al.*, 2002; Fatnassi *et al.*, 2002a, 2002b and 2006) for other types of greenhouses equipped with different insect-proof screens.

With no wind, screens do not appear to change the flow pattern within the greenhouse that corresponds to ventilation caused by the *chimney effect*. However, although air moves in the same way, air velocity drops proportionally to the reduction in porosity of the screen. Thus, at 0.5 m above the ground, which corresponds to the zone in which a greater air intake occurs by thermal effects, the interior air velocity is reduced to between 24 and 29 % of the value obtained without screen (Molina-Aiz, 2010).

Campen (2005) also used CFD simulations and noted that insect-proof screens (with holes of 0.6 × 0.6 mm and 38.9 % porosity) could reduce the ventilation rate by more than 50 %. The study also indicated that the wind direction had little effect on the ventilation rate when an insect-proof screen was installed because the resistance to the passage of the air was very large compared with the direction of the wind. Majdoubi *et al.* (2007) assessed the ventilation capacity through energy balance in a large-size (1.1 ha), tomato growing Almería-type (or Canarian) greenhouse equipped with insect-proof screens. The presence of screens of 10 × 20 threads/cm^2 (35 % porosity with holes of 780 × 250 μm and 280 μm thread) reduced the ventilation rate in this greenhouse by 46 %. When installing insect-proof screens, Kittas *et al.* (2005) found a 33 % reduction in the ventilation of a greenhouse with only side openings (with 50 % porosity).

The measurements conducted with a sonic anemometer by Kittas *et al.* (2006 and 2008) showed normalised velocities that were between 58 % and 65 % lower when insect-proof screens were placed in the openings as well as a reduction in the heterogeneity of the temperature distribution and an increase in the thermal gradient. Moreover, Molina-Aiz (2010) statistically related the temperature gradient between the inside and outside (ΔT_{ie}) of an Almería greenhouse with the screen porosity (φ) and wind speed (v_R) for the four cases analysed using the expression:

$$\Delta T_{ie}\,[\,^{0}\mathrm{C}]=7{,}78167\ -0{,}753656\cdot\varphi\ -0{,}626116\cdot\boldsymbol{v}_R\,[\mathrm{m\ s^{-1}}]$$

Fatnassi *et al.* (2006) also observed how the placement of insect-proof screens in the greenhouses openings produced increases in the temperature gradient compared with greenhouses without screens. Fatnassi *et al.* (2006) used a combination of roof windows opening windward and a side window, and compared greenhouses with anti-Bemisia (holes of 0.78 x 0.25 mm^2 and threads of 0.22 mm) and anti-thrip (holes of 0.18 x 0.18 mm^2 and 0.22 mm thread diameter) protective screens with a greenhouse without screens. They observed that the anti-Bemisia screens produced increases in temperature that were much higher than those simulated in the Almería-type greenhouse (Molina-Aiz, 2010) and a slight increase in the spatial heterogeneity of the microclimate.

The average increase of temperature and humidity was twice that of the greenhouse without screens, whereas for the anti-thrip screen, the increase of temperature and humidity compared with that of the outside was triple. In the Almería-type greenhouse, temperature increases were lower than those obtained by Fatnassi *et al.* (2006), which was primarily because they used equations obtained by Miguel (1998b) to determine the permeability Kp and inertial factor Y of the screen; thus, they overestimated the load loss caused by the screens. Soni *et al.* (2005) observed that a low-porosity insect-proof screen (19 %, with holes of 135μ135 μm and 175 μm thread) can increase the thermal gradient in the greenhouse by 5-10 ºC, whereas a more porous screen (53 % with holes of 780 x 755 μm and 285 μm thread) can limit the gradient to 2 or 5 ºC.

Insect-proof screens promote drastic reductions in the ventilation rate of a greenhouse and generate an increase in the temperature gradient with respect to the outside (Molina-Aiz, 2010; Fatnassi *et al.*, 2006). Thus, the surface of windows should be doubled to maintain adequate levels of ventilation (Montero *et al.*, 2001; Kittas *et al.*, 2005).

2.7. Forced ventilation systems

The principle of forced ventilation (mechanical ventilation) is based on the creation of a flow of air inside the structure through fans located at one end of the greenhouse that extract air and windows on the opposite side that let air in (FAO, 2002).

Through an adequate system of forced ventilation, the thermohygrometric regime of a greenhouse can be controlled more precisely than with natural ventilation, and the concentration of CO_2 inside of the greenhouse can be re-established. The system must be properly designed to ensure the desired renewal rate because improperly designed forced ventilation can be disastrous for the interests of the farmer. For the system to be effective, 45 to 60 air renewals per hour are recommended (ASAE, 1981). However, decreases in ventilation rate caused by the installation of insect-proof screens in ventilation openings should be considered in the initial design.

The cooling capacity of this technique is limited by the external weather conditions. The microclimate inside the greenhouse will tend to approach the external weather conditions as the level of air exchange increases. In Mediterranean regions, the main goals are a reduction of humidity within the greenhouse in autumn and winter and a decrease of the temperature excess in spring and summer. As a collateral effect, an increase of the concentration of CO_2 to levels close to those outside the greenhouse (400 ppm) is achieved, primarily during the central hours of the day when the high level of solar radiation causes an increase in photosynthetic activity and strong consumption of CO_2.

2.7.1. Design recommendations

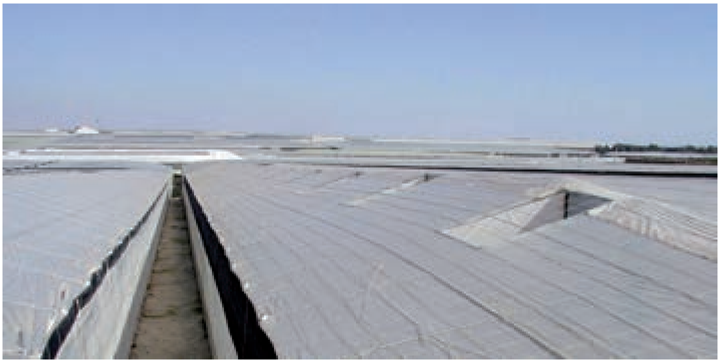
The American Society of Agricultural and Biological Engineers (ASABE) has established a series of recommendations with regard to forced ventilation systems (ASAE, 1981; ASAE, 2003). In addition, the FAO has established some indications for forced ventilation systems in climatic conditions such as those of the Mediterranean region (FAO, 2002):

- Fans must extract air from the greenhouse; exhaust fans improve the distribution of temperature and avoid damage resulting from interior overpressure (FAO, 2002).
- Two successive extractors located at the same wall of the greenhouse should not be separated by more than 8-10 m (Figure 20) and should be located, whenever possible, on the side of the greenhouse opposite to the predominant wind direction. Thus, the external wind speed will not produce a significant effect on the fans (Fuchs *et al.*, 1997). In cases where extractors must be located on the windward band, their ventilation capacity must be increased by 10 % (ASAE, 2003).
- The surface of the air inlet windows located on the opposite side of the fans must be at least 1.25 (FAO, 2002) or 1.5 times (ASAE, 2003) the area of the fans. These windows will be arranged along the entire side opposite the band where the extractors are situated with a length of no more 45 m. The incoming air velocity should not be too high (FAO, 2002).
- It is advisable to connect a variable number of extractors so that they are not all working at the same time in order to facilitate the start of extractors and to enable the modification of the ventilation rate based on environmental variables (ASAE, 2003).

Figure 63. Set of extractors on the side wall of an Almería-type greenhouse. The separation between the centres of the two extractors is 8 m

- The extractor must be kept at a distance of at least 1.5 (FAO, 2002) or 4 times (ASAE, 2003) the diameter of the fan between the point of air expulsion and any type of obstruction. If this is not possible (as is often the case with Almería greenhouses), the extractor should be installed on the roof (Figure 64).

Figure 64. Exterior view of a forced ventilation facility in an Almería greenhouse with air outlets from the extractors located on the cover

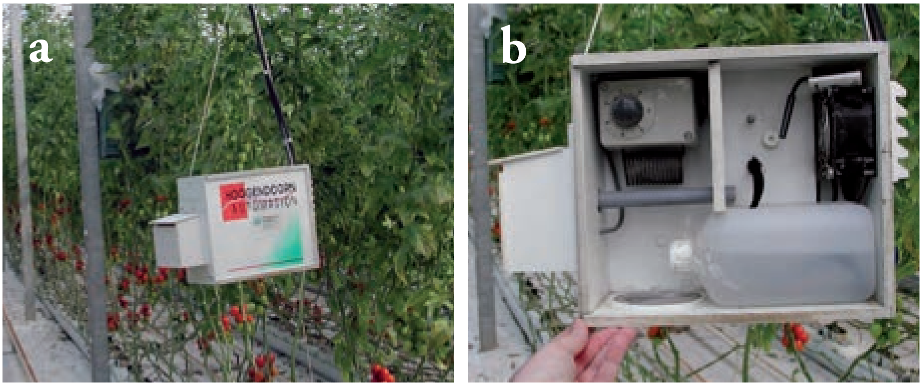


Air intake windows must be operated automatically and be completely airtight when electric fans are not working (FAO, 2002). The fans must have grill screens to prevent accidents, and the output grill screens must open outwards when the extractors come into operation (Figure 65), with their operation controlled by a system such as counterweights (ASAE, 2003).

- Measurement and control instruments of the ventilation system must be protected from solar radiation (ASAE, 2003), housed in boxes of reflective or white material (Figure 66a). Air circulation around the controls must be maintained at a speed of 3 to 5 m s^{-1}, which can be performed with mechanical ventilators that renew the air in the box containing the sensors (Figure 66b).

Figure 65. Protective grill screens on fans open during operation of the extractor (a), and detail of the counterweight opening system (b)

Figure 66. Protection box for a psychrometer for temperature and humidity measurements (a) with a small fan (b) to allow for circulation of the air inside



- Extractors must circulate the previously calculated airflow at a static pressure of 15 Pa. This pressure must be doubled when insect-proof screens or fan-and-pad systems are installed (FAO, 2002). Forced ventilation using extractors generally works with a lower efficiency than specified by its power and at an inferior air exchange capacity because of the pressure drop caused by insect-proof screens located in the openings where the air intake takes place (Fuchs *et al.*, 1997).

2.7.2. Forced ventilation systems installed in Almería-type greenhouses

Forced ventilation (mechanical ventilation) has not been particularly successful in certain Almería-type greenhouses because it is difficult to mitigate the large deficit of air exchange that occurs due to the excessive width of the structures, which can easily reach 100-120 m.

Extractors used in Almería greenhouses are 0.5 to 1.2 m in diameter and have power output values that range from 0.4 to 1.5 kW, with 0.75 kW being the most frequent. The flows they provide vary from 5,000 to 40,000 $m^3 h^{-1}$ depending on the pressure difference between the internal and external environments.

The installation of equipment for forced ventilation systems in this type of structure has a number of disadvantages that greatly hamper larger deployments in the area, including the following:

- Lack of airtightness in the structures.
- High operation costs derived from the large amount of power required for the system and higher number of hours per day of consumption, which is significant at certain times of the year. In addition, a shortage of electricity infrastructure in certain areas can cause a lack of supply that hinders the operation of exhaust fans.
- Excessive greenhouse widths limit their application.

Arellano (2004) evaluated the effectiveness of fan ventilation systems installed in Almería-type greenhouses in which tomato is grown during the spring-summer of the 2003 season and compared the results with those of a traditional system with natural ventilation. He observed that the greenhouse with passive ventilation maintained a lower average thermal jump, with a temperature difference between the inside and outside of the greenhouse of 3 ºC, than the other two greenhouses installed with forced ventilation designed to obtain 15-30 air renewals per hour (4.5 ºC). In addition, the natural ventilation system also recorded lower absolute and relative humidity compared with both systems of forced ventilation.

In terms of total fruit yield, no significant differences in production were observed, although in the natural ventilation system, the fruit reached a greater size and achieved a higher price (Arellano, 2004). Considering both the cost of installation and electrical energy consumption, forced ventilation systems currently installed in the Almería area have not been shown to be economically profitable.

Although the concept of forced ventilation for climate control in greenhouses is sound, greenhouses should use the natural resources of the area where they are installed. In areas with a good wind regime, such as Almería, natural ventilation (passive) may be sufficient to improve the microclimate of the greenhouse, and forced ventilation is only recommended for particular applications. Extractors can also be used as a complement to natural ventilation by applying forced ventilation only when winds are low and the ventilation rate is insufficient.

2.8. Evaporative water cooling systems

In the mid-summer months when outdoor temperatures are higher than the maximum admissible values for plants, evaporative water cooling systems can be used to reduce temperatures and increase air humidity. Various studies have been conducted with different evaporative cooling systems (Montero *et al.*, 1981; Walker and Cotter, 1968; Al-Shooshan *et al.*, 1991; Al-Helal, 1998; Giacomelli, 2002). The main goal of these studies was to determine the influence of evaporative systems on the temperature of the greenhouse and the efficiency of the systems, in which total water consumption and its interaction with the crop as a secondary source of moisture was considered. According to Al-Shooshan *et al.* (1991), transpiration from the leaves of the plant canopy significantly limits the temperature gradient inside the greenhouse.

In recent years, evaporative water cooling has been implemented in many of the new Mediterranean greenhouse structures. Although coastal areas (where greenhouses are generally located) may not appear to be suitable for such systems because the efficiency of the system decreases with humidity, evaporative cooling systems have operated appropriately and have been implemented in nurseries and used for ornamental, fruit, and vegetable crops. This is due to the fact that these systems are necessary primarily during the midday hours, when temperature is too high, which is also the time of the day when humidity is at its lowest level.

These systems evaporate water inside of the greenhouse, producing a decrease in temperature and an increase in humidity. The phase change from liquid to vapour requires energy that is extracted from the greenhouse air, which is cooled, thereby increasing its moisture content. This process creates a heat conversion, from sensible to latent, which reduces the vapour pressure deficit and moderates the evaporative demand.

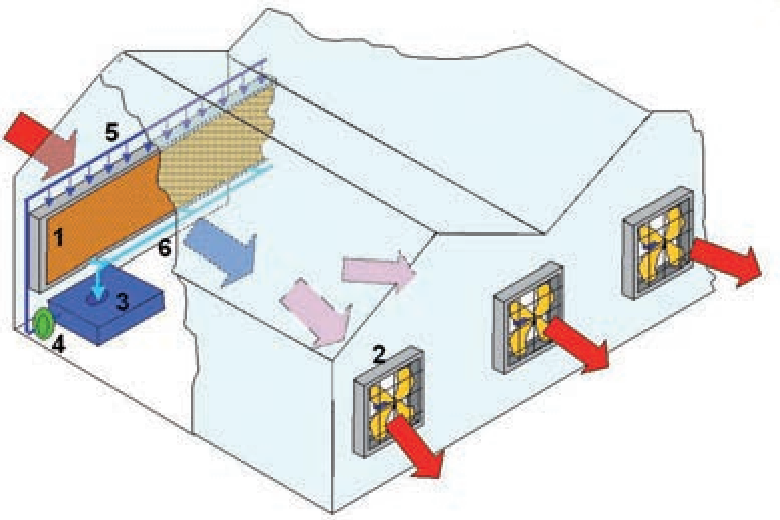
Although there are multiple cooling or humidification systems using this technique, evaporative cooling pads and fog systems have been implemented in Mediterranean greenhouses. Fog systems have provided the greatest degree of success because of the peculiarities of the already built greenhouses, such as their excessive width and lack of airtightness.

The management of evaporative cooling systems is based on the control of the air flow that enters the greenhouse by ventilation and of the evaporated water which generated by evapotranspiration and added artificially by the climate control systems. The supply of air and water in the greenhouse can be determined using mass and energy balances (Boulard and Baille, 1993).

2.8.1. Pad and fan systems

Pad and fan systems work by forcing outside air through permeable pads which are permanently moistened with water; these pads then moisten the air that enters the greenhouse and cool it. In this case, outside air is forced by suction generated by groups of fans inside the greenhouse (Figure 67).

Figure 67. Diagram of a pad and fan system (1. Pads, 2. Fans, 3. Tank, 4. Pump, 5. Water supply pipes, 6. Drain pipes of the panels)



This system requires very airtight structures to prevent air infiltration through gaps or cracks, which would cause a decrease in the overall system performance because part of the flow introduced by the suction of the exhaust fans would not be moistened. This is the reason why these systems have not been implemented in greenhouses with poor airtightness, such as the Almería type.

Fans are usually placed on one side wall of the greenhouse (Figure 68), and the dampened pads are placed on the opposite side, typically on the north side to avoid being shaded. It is also advisable to have the pads facing the prevailing winds in summer. From the dampened pad (Figure 69), airflow passes through the greenhouse, absorbing heat, and it is then transported by the suction of the exhaust fans to the end of the greenhouse located on the opposite side.

Pads of corrugated cellulose (Figure 69) and different types of fibres are used, which can be impregnated with wetting agents in order to increase the evaporation surface and reduce the resistance to air flow. A pump connected to the pad guarantees a continuous drip of water on it. The upper part of the pad is permanently irrigated; the drainage is then recirculated after being filtered, and the amount of water equivalent to the evaporated volume is added to the system.

Figure 68. View of the fans located on the opposite band of the evaporator pads

Figure 69. View of a cellulose pad from inside the greenhouse

The advantages of this method are its operation and control simplicity, and the fact that they do not entail any risk of wetting the leaves of the plants.

The disadvantages of the system of pad and fan panels are as follows:

- Air must be forced through the pad, which causes appreciable resistance to the passage of air.
- Significant moisture and temperature gradients are created along the greenhouse (López *et al.*, 2010, 2012a, 2012b and 2012d).
- Installation, operation and maintenance are expensive.
- A power supply failure would transform the greenhouse into a heat collector.
- Effectiveness decreases with increasing air moisture.
- Continuous operation and poor water quality cause progressive obstruction of the pads, reducing its cooling capacity.
- Water is wasted since the pads are usually over-moistened in order to prevent their obstruction.

The main disadvantage of the pad and fan systems is the lack of uniformity of indoor climatic conditions, which is characterised by rising temperatures and decreasing humidity along the length of the greenhouse and in the direction of airflow. To avoid these problems, the distance between the pads and extractors (width of the greenhouse) should not exceed 45 m. In practice, this limitation implies that its use is exclusive to certain new, industrial-type structures; thus, its use is not recommended with other structures, such as Almería greenhouses.

In certain cases, this system has been combined with shading screens to reduce climatic heterogeneity. Experimental results of combining a pad-and-fan system with shading meshes (Bartzanas and Kittas, 2004) showed interior temperatures that were 10 ⁰C less than the air outside, even during hot afternoons (at temperatures above 35 ⁰C), which was partially caused by the low outdoor humidity and high-efficiency of the cooling system (approximately 80 %). However, when the air path through the greenhouse is large (50-60 m), large temperature gradients and a gradual increase of temperature were observed along the axis formed by the evaporator pads and the extractors, which can reach up to 8 ⁰C at noon when the solar radiation reaches its maximum level.

Thermal gradients are more pronounced in greenhouses with no shading and are much lower in greenhouses with some type of shading method. Similarly, the vapour pressure deficit (VPD) is lower in shaded greenhouses, with values of 1.8 kPa, which corresponds to conditions without water stress. This value is well below that recorded during midday hours for 'raspa y amagado'-type Almería greenhouses in which melon is grown provided with forced ventilation (2.2-3.8 kPa) as well as with natural ventilation (2-3 kPa) (Arellano, 2004). In addition, although very low VPD values were observed for the first few metres behind the evaporator pads, condensation on the leaves of the crops was not detected because the temperature remained constantly above the dew point (Bartzanas and Kittas, 2004).

The temperature of the plant and its relation to air temperature is a key parameter that affects crop growth and the quantity and quality of production. Peet *et al.* (1997) found that increasing the daily mean temperature of the crop from 25 to 26 ^{0}C reduced the fruit weight of tomato as well as their number and seed content, and the effect was nearly the same with an increase from 28 to 29 ^{0}C.

In a non-shaded greenhouse, a mean difference of 2.8 ^{0}C between the plant canopy temperature and air can be achieved using a pad-and-fan cooling system, whereas in shaded greenhouses, this difference is reduced by half (1.4 ^{0}C). This difference can be attributed not only to the shading but also to the greater transpiration flow.

For each pad type, the ASAE (2003) recommends the speed at which the air must cross it, the flow of water that should be provided by linear metre of the pad, the volume of the water tank, and other considerations of special interest to improve the system efficiency.

2.8.2. Fog systems

Fog systems rely on spraying water in the form of small droplets (Figure 70) at a diameter range of 2-60 µm (ASHRAE, 1972) to increase the surface area of water in contact with air.

Because of the size of the drops, it is more of a fine spray than a proper fog, although this is the usual term used for this system. Fog systems use a network of nozzles located over the crops and close to the greenhouse cover. There is usually a nozzle every 2-4 m^2 depending on the configuration of the system.

Figure 70. Mist created by a fog system

For a given amount of water, the surface of water in contact with air increases in direct proportion to the decrease in the size of the drops. Another feature of the drops in this size range is that friction forces resulting from the movement of the droplets through the air are relatively large, thus resulting in lower falling speed (Frenkel, 1986), which is on the order of 0.1 m s^{-1} in still air. As a result, the time spent in suspension is increased, thus allowing for complete evaporation of the droplets. This produces a high efficiency of water evaporation together with the possibility of maintaining the leaves of the plants dry. The resulting high efficiency is due to the fact that, in addition to evaporating water to cool the air, it is possible to evaporate the water in sufficiently large quantities to match the energy absorbed in the greenhouse (under normal conditions, approximately 0.7 kg m^{-2} h^{-1}).

Fog droplets can be generated by different methods: high or low-pressure water forced through a small hole; water stream into contact with an air stream; and centrifugal, ultrasonic and other types of sprayers that use piezo-electric technologies.

The desired greenhouse conditions (radiation, temperature, and relative humidity) depend on the crop's growing requirements, its quality and on plant disease prevention. The majority of crops benefit from high levels of radiation; therefore, solutions that involve a reduction of thermal load through shading are not always suitable. To maintain the other two weather variables (i.e. temperature and air humidity in the greenhouse), two parameters must be controlled: the supply of air that passes through the greenhouse and the supply of water to be evaporated.

Fog systems provide better performance than pad-and-fan systems. In greenhouses with natural ventilation and fog systems, the nozzles are uniformly distributed throughout the greenhouse in order to provide a more homogeneous climate. Moreover, this system can be used in poorly sealed greenhouses as well as in wide greenhouses. These aspects have favoured its implementation on the Mediterranean coast and especially in Almería greenhouses.

Fog systems are also used not only to lower the temperature but also to maintain an acceptable humidity level, especially when the crop is in its early stages of development. Thus, it is possible to advance the date of transplantation, such as to the beginning of August in Almería for a pepper crop when the outside temperature is high. If a fog system is not used, small plants are subject to excessive transpiration that could cause serious wilting problems.

A high fogging dose (1.6 kg m^{-2} h^{-1}) appears to reduce the rate of transpiration of plants. Crop transpiration is a significant factor for the reduction of temperatures inside the greenhouse. However, its effect can be detrimental when high levels of fogging are used or in close-to-saturation conditions (Perdigones *et al.*, 2004).

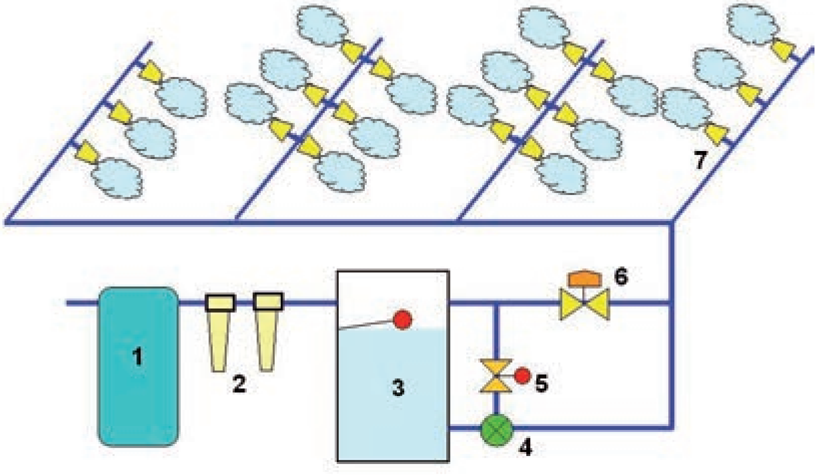
The most delicate elements of the fog systems are the nozzles that generate water droplets because the performance of the system fundamentally depends on them. In high-pressure systems (40 to 60 bar), the water stream collides with an obstacle at the exit and disperses, forming a cone of droplets with diameters less than 20 µm. In low-pressure systems, the water is at a much lower pressure (3 to 6 bar). Ultrasonic nozzles are considered best, but they are also the most expensive (Ferrández-Villena *et al.*, 2002). In this type of nozzle, the compressed air stream strikes a hollow and round resonator situated opposite from the exiting water. The water flows through a wave field and disperses, forming small droplets of approximately 10 µm. Another type of nozzle mixes air (6-8 bar) with water (3-5 bar) inside the nozzle body and provide a lower overall cost and acceptable quality. This type of nozzle is widely used in Spain's eastern regions.

The two fog systems most frequently installed in Almería greenhouses are described below: high-pressure systems, and those systems based on compressed air and low-pressure water.

High-pressure fog systems

Figure 71 shows the basic layout of a high-pressure fog system. The system consists of a water purifier, filters to prevent clogging of the nozzles, water tank, pump with a pressure control valve, and fog nozzles. Water is treated to prevent it from clogging the nozzles and is driven by a high-pressure pump. The system includes electrically operated solenoid valves to facilitate rapid variations in the operating pressure,

Figure 71. Diagram of a high-pressure fogging system*



** 1. Water purifier; 2. Filters; 3. Tank; 4. Pump; 5. Pressure regulator valve; 6. Drain solenoid valve; 7. Nozzles.*

The system is equipped with an anti-return valve to avoid water dripping from the nozzle during transitions between the power-on and power-off states. By using pressures of 25-80 bar and a nozzle density of 0.2 nozzles/m^2, flow rates of evaporated water from 1.2 to 1.7 kg m^{-2} h^{-1} can be achieved.

The efficiency of fogging systems is often limited by an insufficient convection of natural air in the absence of wind (Kittas *et al.*, 2003). Thus, air agitators or extractors are sometimes used to improve the renewal of air so that it does not reach saturation.

The experience gained in countries such as Israel indicates that for uniform conditions, the velocity of air entry in the greenhouse should not exceed 0.5 m s^{-1} and greenhouse lengths should not exceed 35 m. Such configurations are problematic for the water supply system and for their operation and control, which are subject to variations in environmental conditions (Arbel *et al.*, 2003).

Based on these considerations, the following installation scheme is recommended (Arbel *et al.*, 1999): roof windows should be distributed uniformly throughout the greenhouse, exhaust fans should be placed on all sides, and fogging nozzles should be evenly distributed at the height of the structure of the greenhouse. Air enters the greenhouse through roof windows and drags along water droplets that evaporate into the flow. As a result, the air is cooled down due to the water evaporation both at the entrance to the greenhouse as well as along its path through the interior of the plant canopy, and absorbs the excess heat.

A well-designed system produces a high uniformity of weather conditions (± 0.5 ^{0}C) (Arbel *et al.*, 2003). The windward side opening leads to a loss of uniformity of climatic variables along the direction of the wind, which is expressed primarily as a gradual increase in the wet bulb temperature of the air.

A method that provides a suitable control of the fog system in variable climatic conditions (Arbel *et al.*, 1999) combines an on/off system for low-pressure operation and a regulator valve to increase pressure for continuous operation when the thermal load increases. The low-pressure system is set according to the size of the drop and is used in conditions with a marginal need for cooling.

This system is the most effective and achieves the best thermodynamic performance, although it has several drawbacks:

- The use of metallic pipes, special nozzles, and compressors is expensive.
- The nozzles require excessive maintenance because the hole for the water stream can easily become clogged.

However, this is the only fog system that does not wet the crop and fulfils the requirements of temperature decreases and/or maintenance of a certain level of humidity.

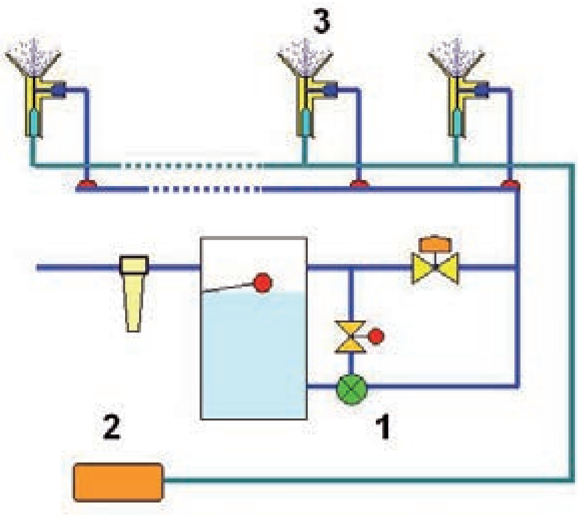
Fog systems with compressed air

In this type of fog system, a stream of air passes through a fogging nozzle, in which water is sucked in by the Venturi effect and then sprayed. The compressed air disperses the water in small drops, and greater air speeds produce smaller diameter droplets. The groove at the end of the spray nozzle causes a change in the airflow lines. Rupture of the fluid vein produces recirculation of the fluid (air-water), which collects water drops adhered to the surface of the nozzle and leads them to the centre of the diffuser, where they are again sprayed. This system uses two networks of distribution pipes arranged side by side, with one circulating the water and the other circulating the compressed air (Figure 72).

The discharge of water is determined by the needs of the crop and environmental conditions. Water flow can be controlled by self-compensating transmitters located in front of each fogging nozzle. Because of these transmitters, a constant water flow can be applied at low pressure. The discharge of the nozzles determines the number of pipes and spray nozzles that are required to achieve the water flow. The pressure should be homogeneous throughout all nozzles to produce a similar water flow.

Using a pumping system, a pressure of 0.8 to 1.5 bar is applied to the water as the air is driven through the nozzles using an air compressor (Figure 73). If the system is planned for operation over long periods, high-performance helical compressors are recommended, whereas if the operation is limited to short periods, alternative compressors are most appropriate.

Figure 72. Diagram of a fog system with compressed air*



* *1. Water pump; 2. Air compressor; 3. Nozzles.*

These systems are widely used in the Mediterranean greenhouses and are being installed in many Almería-type greenhouses (Figure 74), where they are combined with natural ventilation. They have the disadvantage of requiring large compressors, which is sometimes partly resolved by using the equipment for each sector. In theory, these systems can be used to decrease temperature and/or increase humidity and occasionally be used for phytosanitary treatments and foliar fertilisers. However, these alternative uses are not particularly effective because the product is not deposited evenly across the crop.

Figure 73. Air compressor and water pump in a fog system

Figure 74. Detail of a fogging nozzle using compressed air in an Almería-type greenhouse

2.9. Heating systems

2.9.1. Hot-air heating systems

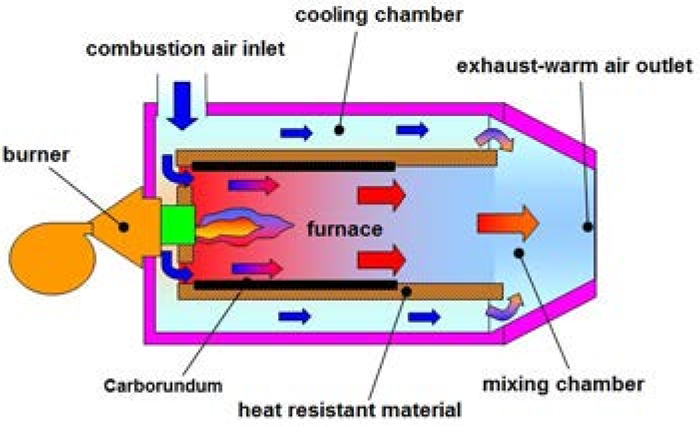
Systems that use air as a heat transfer medium are characterised by rapid heating of the greenhouse because of the low thermal inertia of the air. These systems are observed in greenhouses in which quick responses to possible risks of excessive temperature decreases are required over a short period of time and only a few times a year.

These systems are not appropriate for installations that need an increase in environmental temperature more or less continuously to improve growth conditions for the crop. Because these systems are positioned over the crop, they are close to the roof of the greenhouse, which is associated with high heat loss. However, important thermal gradients within the greenhouse are produced because of air movement, thus producing a great temperature heterogeneity throughout the installation.

Direct-combustion hot-air generators

Direct-combustion hot-air generators are high performance equipment in which fuel is burned (propane or natural gas), thus introducing hot air into the atmosphere as well as exhaust gases resulting from the combustion process (Figure 75).

Figure 75. Diagram of a direct-combustion hot-air generator



These systems are essentially composed of a cylindrical casing coated in refractory material. The area closest to the flame, where the maximum thermal radiation takes place, is also protected by rings of carborundum (i.e. highly refractory boron nitride and carbon-based material). The space between the refractory elements and outer metal casing constitutes the cooling chamber, which circulates air coming in from the outside. At the exit of the casing is a mixing chamber where cold masses of outside air and gases from combustion converge at high temperatures between 300 and 900 ^{0}C.

Certain greenhouses in the Almanzora region (Almería, Spain) use stoves that produce heat by the combustion of diesel oil and through electric resistance. These stoves have a heating capacity of approximately 30 kW. Their main drawback is the expulsion of exhaust fumes inside the greenhouse, although over the short period of time in which they are used, no observable effects on plants have been found (Molina-Aiz, 1997).

This heating system is effective as a method against frost because a simple thermostat triggers the stoves when the temperature drops sharply, preventing temperatures from reaching zero degrees.

Figure 76. Direct-combustion hot-air generators

The majority of nurseries in Almería have hot-air generators that are equipped with a burner and large capacity fan (3,000 to 6,000 m^{3} h^{-1}), which allows them to produce great thermal power (20-80 kW).

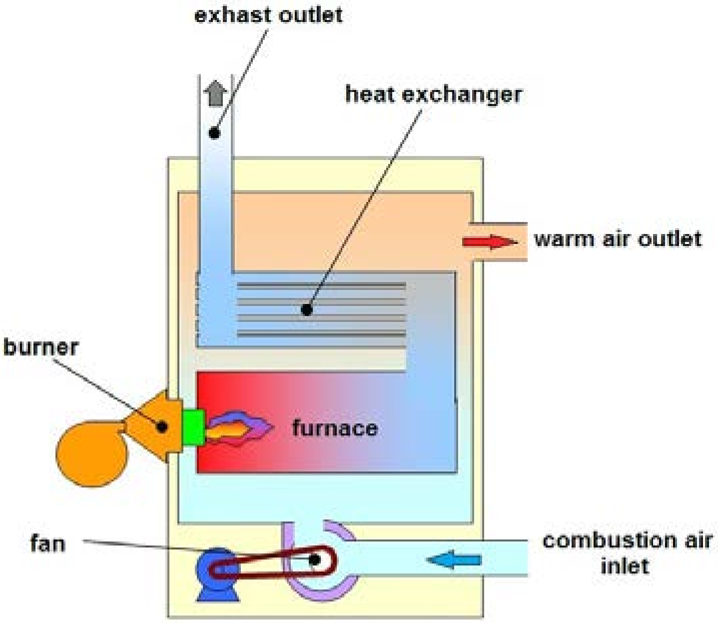
These systems are usually equipped with an electrovalve, thermocouple and safety thermostat, and they may also have pressure switches that shut the unit off in case of a lack of air. In addition, the operation of these systems can be automated through a simple thermostat that operates with the ambient temperature.

Indirect-combustion hot-air generators

To avoid the release of toxic gases inside the greenhouse, which are harmful to people and plants, these generators incorporate heat exchangers that allow the entry of hot air to the greenhouse and expel the gases resulting from combustion. The performance may decrease by 15-20 % compared with previous units because of a loss of heat energy to the exhaust gases.

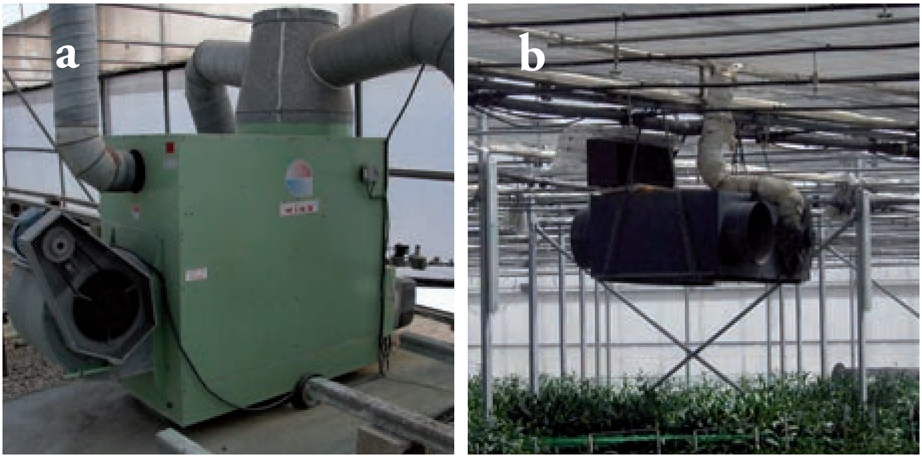
Indirect-combustion generators consist of diesel oil or gas burners, one or two fans, and ducts through which the hot air passes before being expelled (Figure 77).

Figure 77. Diagram of an indirect-combustion hot-air generator



Hot-air generators can be installed on the ground or hung from the structure (Figure 78). When placed on the floor (Figure 78a), a hot-air distribution system must be used in the area occupied by plants to avoid direct outputs to the surrounding plants, which would cause crop damage. Another drawback is the possible loss of useful soil if the unit is placed in the central area of the greenhouse or a lack of uniformity in heat distribution if it is placed at one end of the greenhouse in an effort to prevent the loss of growing surface (Figures 78a and 80).

Figure 78. Indirect-combustion hot-air generators: on the ground (a) and hung from the structure (b)



If the generator is hung from the structure, a blast of hot air can be directly applied without requiring a distribution system. However, this alternative has two drawbacks: potential overloads to the greenhouse structure and application of hot air to the crop. These factors increase the difficulty of heating the crop area and promote heat loss through the greenhouse cover, under which hot air accumulates as a result of thermal buoyancy.

The performance of indirect-combustion heaters hung from the structure can be improved by using a double pipe heat exchanger (Figure 79) to reduce the output temperature of the gasses resulting from combustion to the outside. The main fan delivers air to the burner and drives the smoke out of the greenhouse, passing it through a 0.5 m diameter metal pipe that is approximately 8-10 m long. This system provides 125 kW and has a ventilation flow rate of 8,000 $m^3 h^{-1}$. A second pipe 1 m in diameter and 5-6 m in length is then placed around the first pipe. At one of the ends, a second fan with a flow rate of 4,000 $m^3 h^{-1}$ is placed, and it drives the interior air of the greenhouse through the void of space between both pipes. Thus, heat transfer by forced convection occurs inside and outside of the smaller diameter pipe, increasing the exchange of energy to approximately 25 kW (Molina-Aiz, 1997).

Figure 79. Indirect-combustion hot-air generator in an asymmetrical greenhouse of Campo de Níjar

This equipment allows a thermal jump between the interior and outside air of up to 10 ºC; thus, the crop temperature is maintained above this temperature. Air generators using PE sleeves with holes of approximately 200-250 mm in diameter can improve the distribution of hot air. With those sleeves, the hot-air stream may be able to reach 50 m, whereas without the sleeve, the range is usually 20 m (Montero and Antón, 1994). With these sleeves, the temperature gradient can be reduced to only 1.5 ºC at a height of 1.5 m from the ground (Meneses and Monteiro, 1990). The temperature gradient that develops along the length of the greenhouse depends on several parameters, such as the position and size of the holes (Wells and Amos, 1994) of the PE sleeves, air flow in the pipes, and slope of the terrain in the measured direction (Ray *et al.*, 2005).

Figure 80. Polyethylene sleeves for hot-air distribution produced by an indirect-combustion generator

López *et al.* (2012f) studied the effect of an indirect-combustion hot-air heating system with PE sleeves on the microclimate of a multi-span greenhouse in Almería using sonic anemometers and the effects on plants using a thermal imaging camera. Previously, a study had been conducted on the emissivity of different types of horticultural crops (López *et al.*, 2012c). With a heating power of 88 kW (146.67 W m^{-2} greenhouse), it was possible to increase the temperature in the experimental greenhouse from 7.2 to 11.2 ^{0}C above the outdoor temperature.

The maximum temperature differences ranged between 6.5 ^{0}C and 8.3 ^{0}C, with the lowest temperature in the central area of the greenhouse (last zone in the hot-air path) and not in the south end farthest from the sleeves. To improve the uniformity of the hot-air distribution in the greenhouse, the diameter of the holes should increase along with distance from the heater to offset the pressure and temperature drops along the sleeve (Valera *et al.*, 2013).

An analysis of the heating system showed that heaters managed to increase the average temperature inside the greenhouse from 15.9 ^{0}C (in the non-heated greenhouse) to 17.6 ^{0}C during the crop cycle from October 2011 to March 2012. As a result, the tomato production increased from 5.0 kg m^{-2} to 6.5 kg m^{-2} (Valera *et al.*, 2013). However, the value of this production increase of 0.86 €/m^2 (with an average price of 0.61 €/kg) was much lower than the cost of the consumed fuel at 2.41 €/m^2 (with an average diesel oil price of 1.03 €/L). Under the current economic conditions (low tomato prices and high fuel prices), the use of hot-air heating systems for continuous interior temperature increases led to a reduction in profits for the farmer of 39 %.

Control of hot-air heating systems

The control of air heating systems should be carefully managed because of the high fuel consumption. Control may be performed automatically by using an environmental thermostat placed at the maximum crop height or programmed to operate during a certain period, usually at night.

The ability of hot-air heating equipment to supply heat depends on the type of fuel used (Table 8) to generate energy and the calorific performance of the machine itself.

The thermal performance of the generator is defined as the ratio between the useful output power and nominal power. Useful power is the heat energy transmitted by the generator to heat the air. In the case of direct-combustion generators, all the energy released from the fuel is transmitted to the greenhouse air, so the useful and nominal powers are equal, and performances of 100 % are obtained.

Table 8. Characteristics of the fuels used in the heating systems

Fuel	GCV* (kJ/kg)	PCI** (kJ/kg)	ρ (kg/m^3) (a 20 ºC)
Gasóleo A	44,000	42,500	0.8300
Gasóleo B	44,000	42,500	0.8400
Gasóleo C	43,150	42,000	0.8300
Fuel-oil type 1	42,740	40,650	
Fuel-oil type 2	44,000	39,800	
Natural gas	56,530	51,060	0.7707
Propane	54,190	49,800	1.8785
Butane	53,200	49,000	2.5168

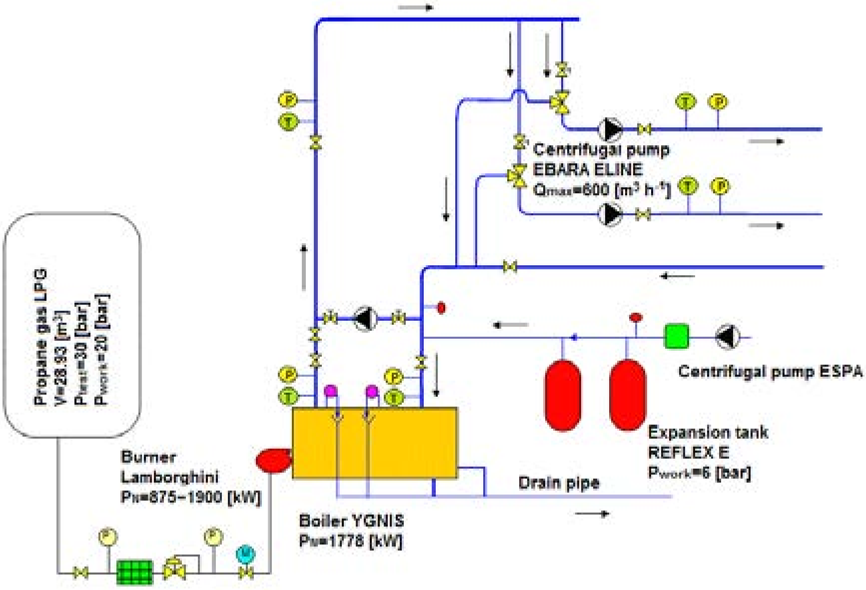
* *GCV Gross calorific value.*
** *PCI Gross calorific value of the fuel.*
ρ *Density.*

2.9.2. Hot-water heating systems

In cold climates when the ambient temperature must be increased for extended periods, the installation of hot-water heating systems is required. A boiler produces heated water using propane gas or diesel oil burners, and the hot water is distributed through a system of pipes throughout the greenhouse, returning to the boiler after transmitting a portion of its heat. These systems warm the air by convection contact with the pipes, and they warm the soil and crops by electromagnetic radiation. Because the pipes are conducting hot water around the plants, lower temperature gradients and a greater uniformity of air temperature with respect to the crop are achieved.

A water heating system consists mainly of the following elements (Figure 81):

Figure 81. Diagram of a heating system for two greenhouses in Almería



- Fuel tank.
- Combustion equipment or burner
- Boiler
- Distribution pipes
- Pump drive
- Expansion tanks
- Safety accessories (pressure switches, thermostats, valves, etc.).

Most hot water heating systems in Almería greenhouses use propane gas as a source of energy (Figure 82), which increases the storage capacity and is cleaner and less expensive than diesel oil.

Figure 82. Propane tanks for a heating system

Boilers

One of the most important components of hot-water heating systems is the boiler, which the system depends on to generate heat. Virtually all the boilers used in greenhouses are fire-pipe types, which circulate hot air through a series of pipes that pass through the body of water to be warmed. Three gas stages are produced inside the boiler, with two in the firebox and one in the smoke pipes. Gases from combustion first pass through the firebox into a post-combustion chamber, where they undergo a turn in direction and finally start passing through the smoke pipes.

Along the entire hot-air pathway inside the boiler, gas retardants can be implemented that increase the turbulence of the flow and the residence time of the gases in the boiler (Valera *et al.*, 2008a). The walls of the gas circulation pipes are wavy to increase surface contact with the water and absorb deformations caused by contraction and expansion processes.

The pressure body of the boiler consists of a high-quality steel cylinder that is closed on both ends (Figure 83). The lateral wall is called a helmet or drum, and the ends are called funds. One of these funds is attached to the body with door hinges, and it houses the burner and provides the opening for access to all the pipes, firebox and burner combustion head so that inspection and maintenance can be performed.

The firebox consists of a cylindrical pipe of undulating walls that joins to another shorter pipe of greater diameter that forms the post-combustion chamber. The large volume in boiler combustion chambers allows them to fully absorb the radiant heat generated by combustion.

Figure 83. Boiler and expansion tanks in a hot-water heating system in an Almería greenhouse fed by propane gas

The boilers used to heat water in greenhouses work with pressures of 10-20 bar and water output temperatures between 60 and 80 ^{0}C, with maximum temperatures of 110 ^{0}C for safety. Using three-way valves (Figure 84), a portion of the return water can be recirculated when not working at maximum power, thus making it possible to regulate the temperature of the emission pipes depending on the needs of the greenhouse.

Heat losses in the hot water distribution network represent an increase in fuel consumption required to meet a given demand; thus, thermal insulation results in fuel economy. The presence of hot surfaces is also a potential cause of accidents; therefore, the surface temperature of the boiler and hot water distribution pipes must be controlled.

The body of the boiler is normally insulated by high-density mineral wool blankets (fibreglass or rockwool) supported by metallic fabric protected by stainless steel sheets (10 to 15 cm thick). For thermal insulation of pipes with nominal diameters of up to 15 cm, the use of covers is advisable (Figure 84). An initial layer of asphalt carton or a waterproofing paint is usually applied over the insulating material (fibreglass or rockwool), which acts as a vapour barrier and the material is then covered with an aluminium or stainless steel sheet.

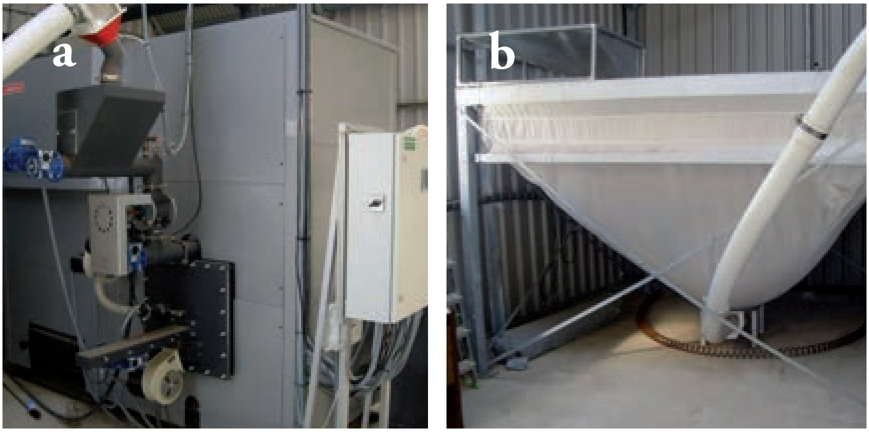
Figure 84. Main piping system of a greenhouse heating system with an insulating covering and three-way valves for temperature regulation

The burners are controlled by a regulating thermostat that turns the burners on and off or modulates the flow according to the needs of the system. A second safety thermostat is also installed. Thermometers should be installed at the exit pipes (Figure 84) and at the return pipes to monitor the working conditions of the system. Another thermometer must be placed in the chimney to measure the temperature of the exhaust gases and determine the loss of energy. In the case of high combustion temperatures greater than 240ºC, a valve must be installed to control the fuel supply to the burner, and additional valves are used to completely isolate the boiler from the rest of the installation.

In recent years, biomass boilers (Figure 85a) have emerged as a feasible alternative for achieving thermal yields similar to those of diesel oil or gas boilers. In addition, automatic control systems allow for easy management of the fuel load in the firebox based on thermal requirements. Thus, the installation of these boilers in greenhouses is increasing. The main problems posed by the use of these boilers is the availability of biofuel supplies (pellets, almond shell or olive pit) with a consistent and homogeneous quality (impurities and moisture content) and the need for a large volume of storage silos (Figure 85b) and maintenance work (much higher than for other fuels). The advantage is the lower price of biomass fuel, and the disadvantages are the difficulty in achieving a homogeneous fuel quality and logistic deficiencies related to its distribution to the agricultural holdings.

When environmental conditions are not favourable, which occurs most years in the province of Almería, biomass boilers require high operating costs because the firebox must remain lit when temperatures are close to heating temperatures. This process involves higher maintenance costs to maintain a suitable temperature in the boiler, even if heat is not required in the greenhouse.

Figure 85. Biomass boiler used to heat greenhouses (a), and storage silo for olive stones (b)



Burners

To select a suitable burner for a given boiler, it is necessary to know the resulting flame size (length and diameter), which must be suitable for the dimensions of the combustion chamber of the boiler.

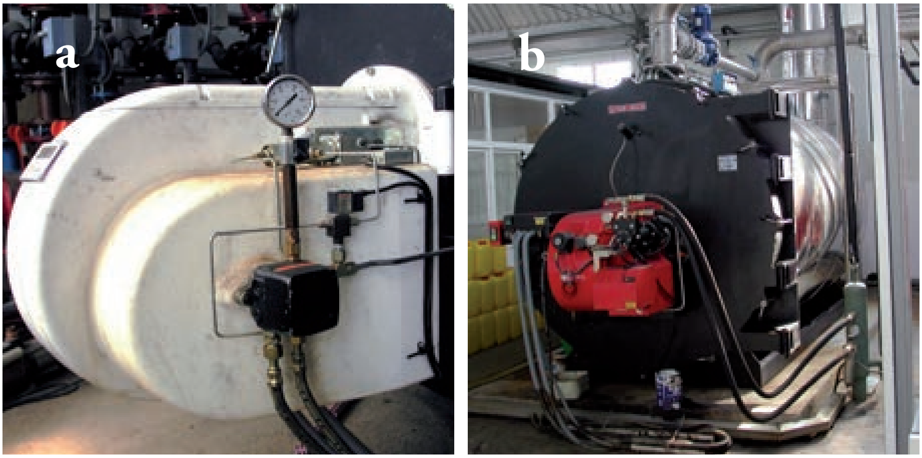
Burners are selected according to the following parameters:

- Type of fuel used.
- Power required by the system.
- Performance guaranteed by the manufacturer.
- Firebox work system (vacuum or overpressure).

In greenhouses, diesel oil (Figure 86a) or propane gas burners (Figure 87) tend to be used, although in some cases, farmers opt to use biofuel (Figure 85a) or gas oil (Figure 86b). The advantage of using gas oil is the low price of the fuel, although in the event of leakage, it is highly polluting, and an auxiliary fuel-tank heating circuit is required to maintain the temperature of the oil higher than the ambient temperature, which is required to reduce the viscosity and allow for handling.

In addition to their shape, the burners are characterised by performance curves relating the pressure in the firebox to the nominal power supplied. When the firebox operates through overpressure, the air for combustion is forced into the unit with a fan.

Figure 86. Diesel fuel (a) and heavy oil burners (b) in greenhouse heating systems



In generators that supply more than 2,000 kW power, modulating burners (Figure 87) that adapt the energy consumption to the needs of the installation should be installed. These burners offer the possibility of regulating the amount of fuel and thermal power in a proportion of 1 to 3, whereas the air for combustion is automatically regulated as a function of the amount of fuel used.

Figure 87. Modulating burner on a boiler for greenhouse heating

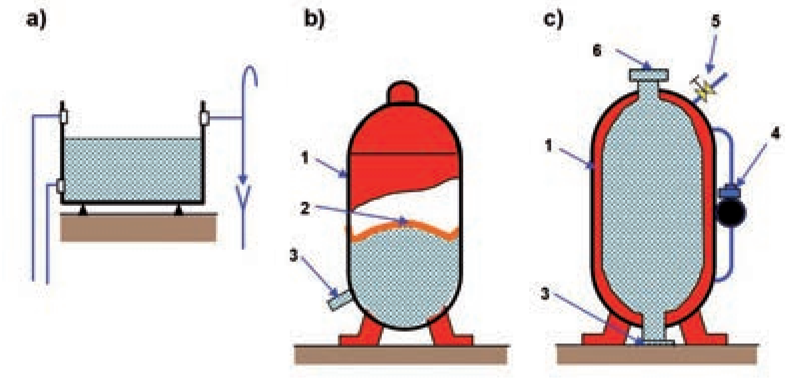
Modulation is performed using a pressure regulator valve in the return line, which allows for silent ignition without explosion and provides start-up power of up to 35 % the nominal power. The fan impeller has an elevated static pressure that decreases the sensitivity of the burner to fluctuations in the overpressure of boiler gases.

Burners of less than 2,000 kW can be installed under a staggered functioning method (Figure 86a), which includes two operating positions and automatic regulation of the flow of combustion air. When heating requirements are not high, the burner generates a single flame, and when additional heat is required to maintain the temperature of the supply water, a second flame is used, which allows the boiler to reach maximum power.

Expansion vessels

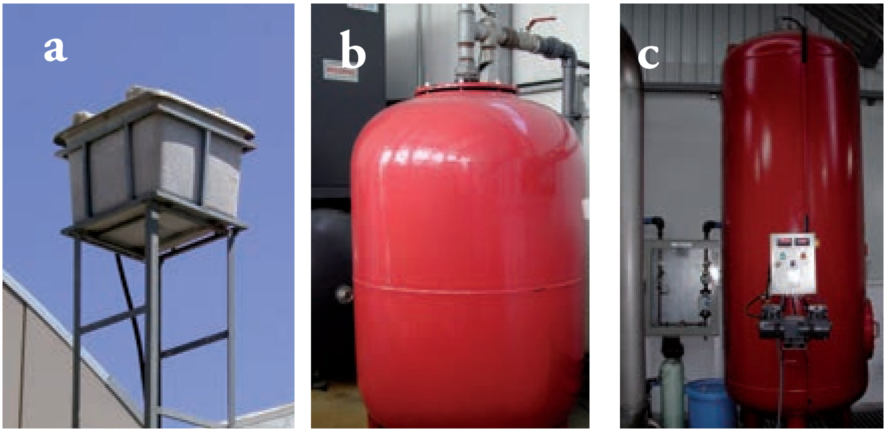
Expansion vessels are used to absorb variations in volume that originate from the expansion of heated water. There are three types of expansion vessels used in greenhouses (Figures 88 and 89): open, closed (with membrane), and closed (with compressor).

Figure 88. Expansion vessels: open (a) closed (without compressor) (b) and closed (with compressor) (c)*



** Components: 1 Expansion vessel, 2 Membrane, 3 Water connection, 4 Control unit and compressor, 5 Air safety valve and 6 Degasser.*

Figure 89. Expansion vessels used in heating systems for greenhouses: open (a), closed with membrane (b) and closed with compressor (c)



Open expansion vessels operate according to the manometric height of the water by means of a reserve tank. The tank is located at a height between 5 and 6 m and placed on a tower (Figure 89a). When the water heats up and its volume increases, the water level in the expansion vessel rises, and when the water temperature drops, the water level lowers. The Reglamento de Instalaciones Térmicas en los Edificios, or Regulation of Thermal Installations in Buildings (RITE, by its acronym in Spanish) has established that a minimum amount of water equal to 2 % of the total content of the installation must remain in the open expansion vessel when the water temperature of the installation is equal to that of the environment. This guarantees the proper manometric pressure throughout the entire circuit and prevents the intake of air (Ministry of the Presidency, 2007).

Closed expansion vessels with membranes consist of pressurised gas that is enclosed by a membrane and pushes the water into the vessel (Figure 89). When the system is out of service and the water is at a temperature of 4 ºC, which corresponds to the maximum density or minimum volume, the membrane occupies the entire volume of the expansion vessel at the operating pressure. As the water heats up, the expanding gas compresses the membrane, forcing the membrane to contract and allowing excess water to enter the vessel. The main disadvantage of this type of vessel is that more than one vessel is required for large volumes of water (Figure 83) because the membrane occupies part of the volume of the vessel. In such cases, the installation of vessels with a compressor is recommended.

In closed expansion vessels with a compressor, when the temperature of the water in the system begins to rise and the water expands, it compresses the air contained in the vessel, which is expelled to the environment through the corresponding safety relief valve. When the water has reached the maximum operating temperature, the vessel is filled with water and maintains a constant pressure. When the water cools and its volume reduces, a control unit activates the compressor, which begins to introduce the precise amount of air required to restore pressure in the vessel to its pre-set operating value.

On-floor heating pipes

Another element that determines the capacity of heat energy transfer by hot-water heating systems is the set of pipes that distributes the heat inside the greenhouse. Different circuit models are designed according to the type and number of pipes and their position with respect to the ground and crop lines.

New installations of multi-span greenhouses are primarily equipped with heating systems that use high-temperature hot-water pipes supported over the ground (Figure 90). These systems are located approximately 15-20 cm high and utilise metal pieces called banks, through which water circulates at high temperature. The temperature of the water in the boiler is usually set to 80 or 90 ^{0}C, and the return water temperature must not be less than 50-60 ^{0}C to avoid condensation in the boiler.

Metal pipes can be composed of steel, which are normally 2 inches in diameter (51 mm), or aluminium (28 mm). Steel pipes can also be used as rails; thus, they can also be used for the movement of transport vehicles, as mobile scaffolding for operators, or in the application of phytosanitary products.

Figure 90. Heating system using metal pipes of hot water

Use of heating pipes around the crop

Another heating method is to circulate water at a temperature between 30 and 50 ^{0}C through corrugated polypropylene (PP) pipes (approximately 15-16 mm in diameter) that are placed among the plants (Figure 91). This system elevates temperature through its greater proximity and number of pipes (4 or 6 per crop line). With this equipment, heat inputs of up to 90 W m^{-2} can be achieved.

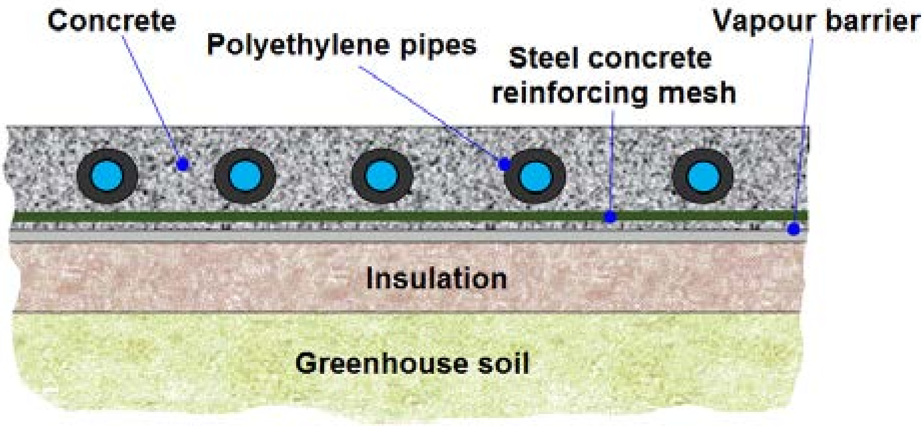
Systems of heating pipes allow for the use of more economical materials, such as high density PE or PP, compared with steel or aluminium pipes (Barrett *et al.*, 1978; Rampinini, 1989). PP pipes are better than PE pipes because if the mixing valve breaks down and high temperature water enters the boiler, PP can better withstand the higher temperatures (ASAE, 1981). Other materials, such as aluminium, can also be used (Figure 94).

Figure 91. Tomato crop of tomatoes with black polypropylene pipes located at the height of the plants

2.9.3. Underfloor heating systems

Underfloor heating systems usually consist of a set of PE pipes buried at a depth of 20 to 30 cm, with water circulating through the closed circuit from the power source (Figure 92). Electrical resistences can also be buried. In cold weather climates and for large surface areas, floor heating can be used for growing in pots, with the system consisting of cross-linked PE pipes, which are covered by a concrete layer and filled with hot water. Savings of up to 20 % can be achieved with these systems compared with the use of air heaters (hot-air generators) or aerial pipelines (García *et al.*, 1997).

Figure 92. Layout of the elements in a floor heating system



This system is used in nurseries in Almería where trays sit on benches over top heating pipes, which are well-supported over the ground (Figure 93a) or hung from the growing tables (Figure 93b). Bench heating is an effective system for raising the temperature of the rhizosphere (Janes and McAvoy, 1983).

Heating the soil takes advantage of thermal inertia by incorporating a large mass into the heating system (Takakura *et al.*, 1994). Plants heated at the root level exhibit increased development (McAvoy, 1992) and production (Moss, 1983). In addition, warming of the soil offsets the effects of low temperatures on ornamental crops (Wai and Newman, 1992).

Figure 93. Heating pipes (under seedling trays) resting on the ground (a) and hung from the tables (b)

This heating system allows water between 35 ºC and 40 ºC to be used (Barrett *et al.*, 1978); it is therefore a way to use alternative energy sources, such as geothermal, industrial waste heat and solar energy (Huys and Mulder, 1981; La Malfa *et al.*, 1993). In addition, the system can take advantage of the existing gradient in soil temperature from depths of 1.5 to 2 m and up to the surface (Baxter, 1994).

2.9.4. Efficiency of heating systems

The cost of heating systems under the climatic conditions of Almería (in ascending order) is as follows: direct hot-air combustion, indirect hot-air combustion, low-temperature hot water, and high-temperature hot water. Although the cheapest system is direct hot-air combustion, it is not recommended because of toxicity issues related to combustion inside the greenhouse (López *et al.*, 2000).

Teitel *et al.* (1999b) conducted a study comparing a heating system with hot water through metal or plastic pipes and a heating system with hot air forced through PE sleeves between the crop lines, and no significant differences were observed in the energy consumption required to maintain nocturnal temperature between 16 and 18 ºC inside the greenhouse.

Crop temperature and energy consumption is a function of the position and temperature of the heating pipes. Energy needs may be increased by 5-10 % by placing heating pipes over the crop at a height of 2.5 m (Figure 94) compared with pipes located at the height of the crop (0.4 and 1.5 m) (Kempkes *et al.*, 2000).

The transfer of heat between the heating pipes and the plants ensures that during the part of the cycle when temperature increases occur, the leaves on the lower part of the plant (where the pipes are located) are generally warmer than the air, whereas the upper part of the plants are colder than the air (Teitel *et al.*, 1999b). Temperature differences at night in a tomato crop appear to be small, and the local effect on the temperature of the leaves due to the heating is fairly limited (Kempkes *et al.*, 2000).

Figure 94. Heating system using hot water pipes of aluminium located at the height of the crop

Hot-water heating systems allow heat to be distributed evenly, which increases their efficiency over air systems. However, when perforated pipes are used to heat the plant, indirect combustion air heating systems have shown efficiencies similar to low-temperature hot-water systems (López *et al.*, 2000).

Through air heating, the leaves are warmer both at the lower and upper part of the plants during the greater part of the heating cycle (Teitel *et al.*, 1999b). However, the need for ventilation to decrease the humidity within the greenhouse increases the consumption of heating energy by 18.4 % in northern latitudes (de Halleux and Gauthier, 1998).

The relationship between the transfer of heat by convection and by radiation changes throughout the cooling period. At the beginning of the period, convection rather than radiation contributes to the total heat emitted by the pipes, whereas at the end of the period the contribution of radiation is significantly greater than that of convection (Teitel *et al.* 1996). Heat transmission caused by radiation is between approximately 41 and 52 % of the total heat provided by the heating pipes.

Numerous control methods have been designed based on simple parameters, such as temperature (Bailey, 1985), solar radiation (Calvert and Slack, 1975) or simulated energy flow in the greenhouse (Duncan *et al.*, 1981; Fuller *et al.*, 1987). The most widely used method of controlling heating systems is according to the interior air temperature of the greenhouse and exterior air temperature. In the simplest case, thermostats are used for control, whereas in complex cases, a climate control computer program is used to turn the heating equipment on and off.

Using an off-on control causes cyclic variations in the crop and greenhouse air temperature, and differences between these temperatures also vary in a cyclical manner. A more sophisticated alternative to off-on controls consists of regulating the flow of fluid heating (air or water) to maintain a constant supply of heat according to heat loss, which produces constant air temperatures inside the greenhouse and around crops. To establish such control, the heating needs in short time intervals (on the order of seconds) must be determined by establishing an energy balance in the greenhouse, which estimates heat loss in the greenhouse over time. These control systems are more complex and require several types of microclimatic data. Every day, additional greenhouses are equipped with computer systems and weather stations; thus, flow control systems can be a valid alternative for the future.

Variable-drive displacement pumps

Variable-flow heating systems equipped with pumps with a frequency inverter maximise energy savings and optimise system operations. Variable displacement pumps (Figure 95) propel hot water through the pipe network that distributes heat inside the greenhouse, thus maintaining a constant pressure even when heating requirements vary.

Figure 95. Variable-drive displacement pumps for the distribution of heating water in greenhouses

Frequency inverters are responsible for regulating the flow of the secondary circuit according to the pressure variations of the network, which produces heat demands at every given moment. Compared with a constant-flow distribution system, variable-flow systems can produce constant water temperatures and provide energy savings because the water flow is only pumped through the system as needed.

Two-boiler system

Boiler heating systems are often too large to provide a given capacity margin (Gardner, 1984). Therefore, boilers generally supply an adequate amount of hot water, although they usually operate at low performance levels (Liao and Dexter, 2004).

Figure 96. Two-boiler system in Almería greenhouses for hot water generation

Greenhouse heating systems must operate under highly variable climatic conditions. At the end of autumn when the heating period begins and at the start of spring when the heating period usually ends, the thermal requirements are well below the maximum heating power. Thus, boilers operate well below their maximum capacity, which leads to a significant decrease in efficiency.

To maximise performance throughout the seasons, the installation of two equal boilers that supply half of the power required in the greenhouse is recommended (Figure 96). Thus, during the periods in which large heat contributions are not required (spring and autumn), a single boiler at maximum power can be run, with the other shut off. When heating needs increase with the arrival of winter, the second boiler can be run to take advantage of the full potential of the system.

Water tanks for thermal energy storage

Thermally isolated hot-water storage tanks (Figure 97) can be used when CO_2 is produced by combustion for carbon enrichment in periods of low heating needs (such as during the central hours of the day), and in greenhouses with electrical cogeneration facilities in periods in which the greenhouse does not require heating.

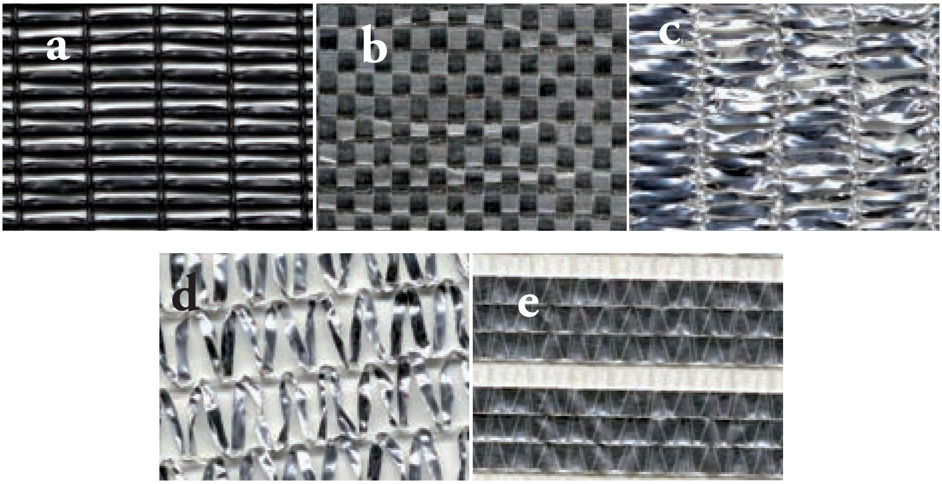
Figure 97. Hot-water storage insulated tanks for heating of greenhouses in the Netherlands

An increase in the concentration of CO_2 in a greenhouse during the day has a positive effect on the growth of many crops. The necessary CO_2 can be produced by burners that release a significant amount of heat. In the current economic and environmental conditions, the waste of this residual heat is difficult to justify. An effective method of preventing these losses of heat is to use tanks to store hot water when heat is not required in the greenhouse. Subsequently, when the temperature in the greenhouse decreases, hot water is introduced from the tanks. Thus, when the burners are operating for the production of CO_2, which is usually during the day, hot water generated in the boiler is sent to the storage tank, and during the night, the residual heat is used to heat the greenhouse.

2.10. Shade nets, thermal screens and darkening screens

Textile meshes can be considered climate control techniques and are increasingly used in intensive greenhouse horticulture. The use of these agrotextile materials is aimed at modifying the radiation that reaches the plants, both in quantity and quality. Its use reduces the amount of luminous radiation falling on the plants during the day and reduces the loss of long-wave radiation emitted by the plants at night. As a result of this modification of light and energy balance in the greenhouse, a variation of other climate parameters, such as temperature and humidity, is produced, which directly affects the photosynthesis and transpiration processes of the crop, altering their development and productivity.

Figure 98. Different types of shading meshes and thermal and darkening screens



Depending on the objective, three types of agro-textile materials can be distinguished:

- *Shade cloths*: used to reduce the incident radiation on the plants during warm periods, in which excess energy produces an extreme increase of temperature inside the greenhouse that might be harmful for horticultural crops (Figure 98a).
- *Darkening screens*: used to decrease the incident radiation on the plants by reducing the light intensity and adapting it to the needs of certain species of ornamental plants or flowers. Completely opaque screens are used to limit the hours of daylight and regulate the photoperiod of crops (Figure 98b).
- *Thermal screens*: used to reduce energy loss in the form of long-wave radiation emission at night (Figure 98c,d,e) and widely associated with heating systems.

When the different sheets of the screen have no gaps in between, they are referred to as closed, whereas sheets of mesh with gaps are referred to as open, with the latter being the most usual type in the shade nets because they allow better air circulation.

Net radiation below the screen depends on the percentage of shade provided by the net and the type of mesh material. To increase the reflection of the screen, the sheets can be metallised with aluminium, which is known as aluminised screens. In cases where the greenhouse is sufficiently ventilated, these fabrics absorb less radiation, acquire less heat, and thus achieve a greater decrease in temperature.

Depending on where they are installed, these screens can be used for exterior or interior purposes. Screens can cover the greenhouse on the outside or be placed under the roof, leaving an air chamber between the screen and greenhouse cover. Exterior placement is more efficient because it produces lower temperatures inside the greenhouse, although it presents a major limitation in areas of strong winds. Today, external shade nets are fixed to the greenhouse cover to mitigate this drawback.

Thermal screens and shade meshes can be deployed and retracted with automated systems (Figure 99) using a timer or weather sensors (primarily for radiation and temperature) integrated in a climate controller.

A wide range of nets are available with different percentages of transmission, reflection and air porosity. In general, aluminised meshes provide the best performance in warmer climates as long as their reflection capacity does not decrease due to the growth of algae over time or the build-up of dust and dirt deposits. The operative lifespan of shading meshes is usually between 4 and 8 years, whereas thermal screens with anti-UV-radiation treatment can reach up to 10 years.

Figure 99. Suspended thermal screen that is retracted in a sector and deployed in the adjacent sector

2.10.1. Shade cloths

Shade nets combined with good ventilation reduce insede greenhouse temperatures and decrease crop transpiration. These nets should transmit the greatest possible amount of PAR and reflect the maximum amount of short infrared radiation from the sun.

The majority of shade nets are black or aluminised (Figure 100), although they are available in different colours. However, coloured meshes have the disadvantage of absorbing part of the radiation spectrum, which causes a double negative effect of a decrease in PAR and an increase in the temperature of the nets, and therefore of the temperature inside the greenhouse.

Shade nets on the outside of a greenhouse produce a greater reduction of the temperature inside the greenhouse. Heat generated by temperature increases in the mesh caused by the absorption of radiation is released on the exterior by wind action. However, external meshes have a more limited lifespan, require structures with higher durability, and have a rather complicated assembly and automated management. In addition, such installations are discouraged in areas such as the province of Almería, where high winds are present.

Figure 100. Greenhouse with shading screens

In the case of interior nets, the absorbed energy is transformed into a heat flow that must be removed by ventilation. The nets placed inside the greenhouse hinder the vertical movement of air from the growing area and the passage of hot air towards the roof windows. As a result, it is important to ensure that shading is combined with an efficient ventilation system that allows heat elimination through the extraction of hot air from the inside of the greenhouse.

2.10.2. Thermal screens

Thermal screens increase the minimum temperature of the greenhouse, crop and soil at night by reducing long-wave radiation loss during the night and by air renewal. These screens also decrease the transpiration of the crop at night and therefore reduce the heat consumed by evapotranspiration.

The placement of closed thermal screens (without gaps between the fibres that constitute the screens) between the crop and the greenhouse cover can also reduce energy transfer by convection through the greenhouse cover. This reduction is greater the lower the infrared emissivity of the screen, as occurs with aluminised screens (Bailey, 1978).

The main effects these screens produce in greenhouses are the following:

- Increase of the minimum temperature of the greenhouse by 2-3 ºC at night because of the decrease in thermal radiation lost during the night (Baille *et al.*, 1984; Plaisier, 1991).
- Increase of 1 to 2 ºC of the plant and soil temperatures (Bailey, 1978; Boesman *et al.*, 1984).
- Reduction of heat losses by air infiltration because of the reduced effect of wind (Baille *et al.*, 1984).
- Significant reduction of the transpiration of the crop at night (de Graaf, 1985) and heat consumed in the evaporative flow (Deltour *et al.*, 1985).

The best results are obtained when screens are deployed at the end of the day and retracted in the morning (Pirard *et al.*, 1994). These screens decrease fuel consumption for heating from 20 to 46 % depending on the type of screen used (Table 9), and when used at night, they also promote energy storage in the soil and crop, having a positive impact during the day (Pirard *et al.*, 1994).

A thermal screen should have the lowest possible transmission factor and the highest possible reflection factor in the medium and long infrared spectra (2.5-40 μm) (Tesi, 1989).

Figure 101. Greenhouse with aluminised thermal screens

Table 9. Properties of different types of thermal screens. In percentage

Materials	Transmission-Reflection of solar light*	Transmission-Reflection of infrared radiation	Solar diffusion	Energy savings
Low-density polyethylene	84-14	42-5	80	32.5
Woven polyester	39-58	5-2	29	42.0
50 % aluminised polyester	37-68	18-18	32	-
75 % aluminised polyester	19-68	9-27	16	-
100 % aluminised polyester	0-82	0-36	0	46.5

**Angle of incidence of sunlight of 45º.*

Source: Baille *et al.* (1985); Pirard *et al.* (1994).

A thermal screen should have the lowest possible transmission factor and the highest possible reflection factor in the medium and long infrared spectra (2.5-40 µm) (Tesi, 1989).

These screens are usually composed of PE or polyester with one or two aluminised sides (Table 9). The most efficient screens are those with two aluminised sides (Figure 102) because they achieve a higher crop temperature and are thus an acceptable shading alternative in certain circumstances. If only one side is aluminised, it should face the outside (Baille *et al.*, 1985).

Figure 102. Double-sided aluminised thermal screen

2.10.3. Operation

Different types of operation schemes can be distinguished according to the placement of the shade nets and thermal screens in relation to the structure of the greenhouse:

Screens suspended horizontally. The screen is extended until it is completely flat and parallel to the ground. The height at which the screen is placed must be the maximum possible in order to leave the maximum volume between the crop and the screen for correct air circulation. Closing of the screen or net is performed by folding (Figure 5).

In this type of installation, the screen is suspended under a series of metal profiles and cables that are joined by hooks linked to the polyester fibres of the screen. Rotational movement transmitted by a gear motor (Figure 103) to a control bar becomes longitudinal movement through a rack-and-pinion system. The rack can be bound to a metal drive pipe that slides over pulleys and communicates movement to all attached drag links in the different cloths or meshes within each module of the greenhouse.

Figure 103. Geared motor that drives the suspended thermal screens

In other cases, the rack is directly linked to a cable that powers the opening and closing mechanism of the screen by moving the attached drag links. However, possible mismatches may occur between the different screen panels and produce differential stretching along the cable, which must be corrected with a series of tensioning elements.

As a less expensive alternative, the cable that transmits motion to the screen can bind directly to the control bar, thus replacing the rack-and-pinion system.

Exterior rolling screens. The rolled screens are placed on the roof of the greenhouse on both sides of the ridge, and the closure is performed at the highest part of the greenhouse.

Interior rolling screens. The rolled screens are placed around a rotating motor-driven control bar that retracts and deploys the screen automatically. These screens can be installed tilted, following the slope of the roof or vertically for placement on the sides and fronts with the aim of complete closure of the greenhouse.

Screen rolling is performed with tubular motors that move on aluminium profiles via union guidelines. Motors support slotted pipes that are inserted at the end of the mesh so that the force provided by the rotation of the motor rolls the screen as it moves upward. By rotating in the opposite direction, the weight of the motor and control bar causes the downward displacement of the mesh.

It should be noted that thermal screens and shading meshes constitute important technological improvements of greenhouses and provide beneficial side effects, such as energy saving of heating systems. However, when installed to decrease temperatures in warm areas, these systems must be accompanied by good ventilation, which could be in the form of forced ventilation (by fans).

2.10.4. Darkening screens

Darkening screens are usually composed of a double mesh, with a black polyester layer and an aluminised layer on top. These screens can provide almost total blackout conditions, allowing perfect control of the day length for ornamental crops such as chrysanthemum, Kalanchoe and Euphorbia. Such screens are used to modify the photoperiod and induce flowering in the appropriate commercial period.

Although these screens are nearly opaque to light, they should be permeable to the flow of water vapour so that unwanted increases in humidity are not produced when the screen is extended. Darkening screens can also be formed by a layer of aluminium, layers of black and white, or even a double layer of white polyester, which would have higher solar radiation transmissivity (approximately 10 %).

Double screens with one white face are also suitable for use in greenhouses where artificial lighting is used. Because of the low light transmissivity of these screens, loss of light to the outside is reduced, which achieves the double benefit of preventing possible interference with upcoming crops and an increase in the amount of light available for growing inside the greenhouse because of the high reflection of the white inner layer.

Figure 104. Darkening screen on the side of a greenhouse

2.11. Simple energy saving methods

2.11.1. Double walls

Greenhouses with double walls (Figure 105) are an effective method against low winter temperatures and can be considered an alternative to the heating systems in the Mediterranean coast (González and Martínez, 1981). In addition, these installations produce better results than single walled greenhouses (Papadopoulos and Hao, 1997).

This type of greenhouse is built by adding a second layer of 50 or 100 µm thick PE (125 or 250 gauge). This method can reduce heat losses by 40-50 % (Bianchi, 1989; Gutierrez Montes *et al.*, 1992) and heat consumption by up to 57 % (Bauerle and Short, 1977). As a result, temperature increases in the greenhouse of up to 8 ºC (Rosocha, 1993) and temperature increases for the plants are obtained (Amsen, 1981).

Figure 105. Installation of a double roof in a nursery

This climate control system is still not widespread in Almería greenhouses, and its use is limited to certain nurseries where climate control is important for the correct development of seedlings, which are more sensitive to temperature changes than developed plants.

The double wall in the greenhouses not only modifies their temperature but also changes the moisture, light, and CO_2 available in their interior. As consecuence of reduction air infiltration, heat loss is reduced primarily at night. CO_2 levels may also be reduced; therefore, carbon enrichment may become necessary (Bauerle and Short, 1981). However, the main disadvantage of these systems is that their fixed installation produces a significant loss of light during the day (Ferare and Goldsberry, 1984), which can be as high as 10-15 % (Plaisier, 1991). This reduction can lead to frailty in crops with high light requirements, such as melon (Sánchez-Montero *et al.*, 1989).

2.11.2. Semi forcing tunnels

Low tunnels (Figure 106) are small structures covered by a layer of PE that is 50 µm thick and between 0.5 and 1 m wide. They are only used for the early stages of growth because in subsequent stages, the leaves touch the plastic, which must then be removed to allow plant growth. These tunnels increase the temperature of the air surrounding the seedlings and reduce energy losses by infrared radiation at night. Placing the tunnels above the heating pipes allows large energy savings by greatly limiting convection heat losses to the rest of the greenhouse.

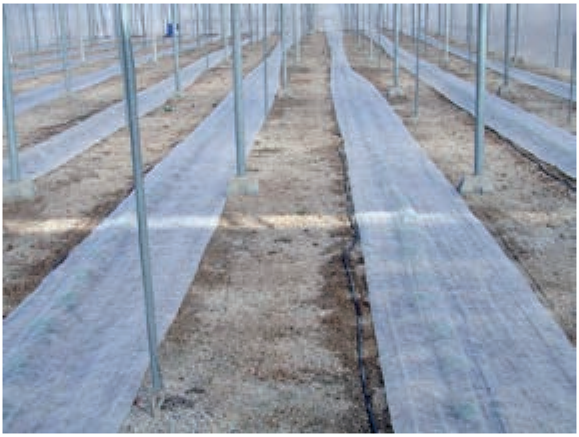
Figure 106. Greenhouse with low tunnels and thermal screens

2.11.3. Thermal blankets

An alternative to the use of low-tunnels is the application of thermal blankets that reduce heat loss from the soil and plants due to infrared radiation and convection into the air, thus allowing an increase of their temperature. These blankets can be manufactured using thin PP filaments stabilised against UV radiation to reduce degradation by the direct action of the sun. The blanket is a light thin sheet of tissue (with an approximate weight of approximately 17 g m^{-2}) that has a high air permeability and a high solar radiation transparency of approximately 95 % (Shukla *et al.*, 2006), which allows the crop to develop properly. These thermal blankets can also be placed on crops up to 1 m tall (Barral *et al.*, 1999), which increases the temperature of the air surrounding the plants by 2-3 ºC at night and in the early hours of the morning and reduces the temperature by 3-4 ºC during the central hours of the day (Ghosal and Tiwari, 2004).

In Almería, these blankets are used for early spring crops. They are placed directly over the soil covering the seedlings (Figure 107), thus preventing damage caused by temperature drops.

Figure 107. Thermal blankets covering the seedlings



2.11.4. Greenhouse partitioning

The creation of different compartments inside the greenhouses for ornamental crops or in nurseries, where it is common to have crops with different thermal needs, can significantly reduce heating and cooling requirements. Partitions are created through the vertical placement of PE sheets (Figure 108). This technique can also be used in long greenhouses located on plots with steep slopes to prevent the displacement of hot, lower density air towards the highest part of the greenhouse.

Figure 108. Interior partitions with polyethylene sheets inside a greenhouse

2.12. Carbon-dioxide enrichment systems

The enrichment of greenhouse air with carbon dioxide is an effective method of increasing crop production (Nederhoff, 1988). This climate control technique is recommended to prevent declines in photosynthetic activity caused by decreases of CO_2 concentrations in the interior of the greenhouse due to the relative airtightness of the structure. This usually occurs in spring and summer (Hand, 1984) when carbon dioxide consumption rises above its availability because of the higher photosynthetic activity in the plants induced by the increased availability of radiant energy.

Carbon dioxide enrichment using pure CO_2 is the safest and most controllable method of CO_2 incorporation (Nederhoff, 1990). In this case, carbon dioxide supply is independent of the heating system. A disadvantage of this technique is its higher price compared with that of other systems; however, the cost of the CO_2 supply and equipment has significant local variations. In Almería, the approximate cost is € 150/t, which is in addition to the rental of CO_2 tank of 400 €/month.

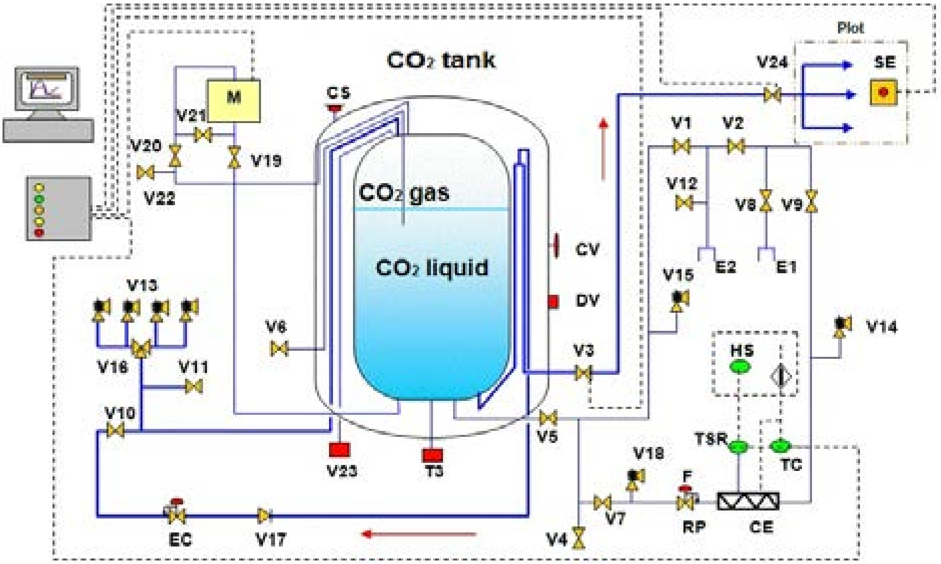
2.12.1. CO_2 distribution in the greenhouse

The equipment required for the direct supply of CO_2 to the lower part of the plants consists of a tank that stores CO_2 in the liquid state (Figure 109), an expansion vessel set where liquid is converted to a gaseous state by means of a decrease in pressure, a primary piping system, and distribution pipes to the crop (Figure 112).

Currently, this system is being used in modern, recently built facilities in the province of Almería, including large farms with multi-span or *Venlo* structures that allow for the control of losses caused by leakage. In certain cases, the evaporators are encapsulated inside a metal tank (Figure 111) equipped with a heating system, which allows better CO_2 vaporisation. The liquid CO_2 used for horticultural purposes is usually obtained from industrial chemical processes, and partly from natural sources and biochemical processes.

Figure 109. CO_2 tank and evaporator circuits for carbon-dioxide enrichment in greenhouses

Figure 110. Layout of a carbon dioxide enrichment facility



V1	Liquid phase filling valve
V2	Gas phase filling valve
V3	Outlet valve towards the greenhouse
V4	Low point drain valve
V5	Isolating valve
V6	Overflow valve
V7	Pressurising circuit valve
V8	Gas equilibrating valve
V9	Heater isolation valve
V10	Economiser isolation valve
V11	Air valve
V12	Flexible drain valve
V13	Safety valves
V14	Heating circuit safety valve
V15	Heating circuit safety valve
V16	Three way valve
V17	Check valve
V18	Regulating circuit safety valve
V19	Lower level valve
V20	Higher level valve
V21	By-pass level valve
V22	Outlet pressure gauge valve
V23	Pump return valve
V24	Feeding valve
E1	Balancing intake
E2	Filling intake
E3	Pump feeding intake
CE	Electric heater for pressure release
CS	Safety enclosure
CV	Vacuum sensor
DV	Vacuum mechanism set
EC	Economiser
F	Filter
M	Level gauge
RP	Pressure regulator
SE	CO_2 level sensor
TC	Thermostat control
TSR	Safety thermostat in resistance
PC	Computer controller
CON	Automatic control

Figure 111. CO_2 evaporator with an auxiliary heating system

Carbon enrichment must be performed through a system of transportation and distribution that produces a homogeneous supply in the greenhouse. The best supply method is through a piping system. The application of CO_2 in the irrigation water does not appear to increase the rate of photosynthesis of the crop (Nederhoff, 1990). Pipes can consist of irrigation tape with inserted drippers of 1 L h^{-1} (Fig 112a) or flexible transparent PE sleeves (Figure 112b).

Figure 112. CO_2 distribution systems placed below the channels where the crop is located in substrate using irrigation tape (a) and flexible sleeves (b)

2.12.2. CO_2 supply control

Environmental CO_2 concentration control requires properly calibrated measuring equipment, which is usually an infrared gas analyser (IRGA).

Figure 113. Measuring box with CO_2 concentration sensor

Carbon dioxide enrichment is conducted according to a supply strategy, and in the simplest case, CO_2 is supplied at a constant rate or concentration independent of the ventilation system. More sophisticated strategies are based on physiological and economic principles that consider concentrations between 700 and 1000 vpm to be within physiologically optimal levels for growth and production of horticultural species.

Carbon dioxide enrichment with concentrations of 900 vpm increases the accumulation of dry matter by more than 40 %. In cucumber and tomato crops, these concentrations lead to increases in early production of 11 and 15 %, respectively (Fierro *et al.*, 1994), whereas in the ornamental crop Calathea crocata, they advance flowering by 10 days (Huylenbroeck and Debergh, 1993).

In autumn, winter and spring during daylight hours and when thermal conditions allow windows to be closed without increasing temperatures to undesirable levels, CO_2 above the atmospheric level can be added.

In poorly ventilated greenhouses with low window surfaces, during periods of the day with high photosynthetic activity, CO_2 concentrations can drop to values lower than the average atmospheric content. In these conditions, carbon dioxide can be supplied so that the inside concentration matches the outside concentration during daylight hours (Savé *et al.*, 1996).

The CO_2 concentration and PAR accumulated during the day are two of the main variables that affect the growth of plants in a greenhouse. Aikman (1996) has shown that crop production can be improved by the simultaneous addition of lighting and carbon dioxide enrichment. Different combinations of PAR accumulation and CO_2 concentrations may promote the same levels of crop production (Both *et al.*, 1997). However, the typical constraints of greenhouses in Almería significantly hinder the incorporation of these techniques.

The application of optimal combinations of daily integral PAR and CO_2 obtained by an optimisation model (Ferentinos *et al.*, 2000) can significantly reduce the operational costs of a greenhouse, especially during winter months when the greenhouse ventilation rates are low or even non-existent and only infiltration leaks occur.

In days with ventilation rates (including infiltration) of 3 or 4 air renewals per hour, if the integral of ambient PAR is sufficiently low, the greenhouse microclimate can be improved by the addition of CO_2. For high ventilation rates, enrichment with CO_2 becomes economically prohibitive because of the high rate of gas loss to the outside. In such cases, the common practice of maintaining a suitable environmental concentration to maintain a daily PAR interval of 17 mol/m^2.day is often the most economical strategy (Ferentinos *et al.*, 2000).

2.12.3. Optimisation of carbon dioxide enrichment

A large number of factors can be optimised by means of computer programs that control carbon dioxide injections, such as ventilation, light intensity and wind speed, with the possibility of their assessment in financial units, leading to production increases with low costs related to CO_2 enrichment (Nederhoff, 1988).

Analytical relationships can be used to determine the optimum concentrations of CO_2 as a function of incident radiation and ventilation rate and the relationship between the price of the crop and the cost of gas (Chalabi and Critten, 1990). The main obstacle with these methods is the difficulty in determining the cost of production, which is subject to large fluctuations even over small periods.

In cold climates, carbon enrichment with CO_2 is normally performed in greenhouses without ventilation. When ventilation is required in greenhouses at low renewal rates, simultaneous enrichment and ventilation may be an economical alternative.

Carbon dioxide enrichment in greenhouses in hot climates is restricted by ventilation requirements, which forces certain farmers to conduct periodic enrichments, where the contribution of CO_2 and ventilation alternate several times per hour.

In climatic conditions with a great need for ventilation, carbon dioxide enrichment can follow two primary strategies:

- Continuous enrichment without ventilation during the early hours of the morning (07:00-10:00 h) and at the beginning of the afternoon (15:00-16:30 h) (Ioslovich *et al.*, 1995).
- Intermittent enrichment alternating with ventilation several times per hour (Enoch, 1984).

During warm and dry days, which are typical of semi-arid climates such as that of the province of Almería, the temperature of the plant canopy is the main limiting factor in the process of photosynthetic assimilation. In these conditions, carbon dioxide enrichment is only effective during the morning before the ventilation rate increases to cool the crop (Seginer, 1990).

For the simultaneous supply of CO_2, it is convenient to use two ventilation rates: a low rate for the period of enrichment and a higher rate when CO_2 is not provided. This strategy is used in Almería greenhouses that employ carbonic fertiliser systems, which inject CO_2 to 700 vpm when the windows are completely closed and to 350 vpm when windows are open.

The optimum enrichment strategy for maintaining specific levels in the greenhouse depends on the external climate. Continuous enrichment is most appropriate when the weather conditions do not vary over 10-20 minute periods (Ioslovich *et al.*, 1995). The control of CO_2 becomes more complicated when fluctuations occur in the greenhouse environment. During warmer months, greenhouse ventilation increases the difficulty of maintaining CO_2 levels greater than the outside concentrations because ventilation must be stopped continuously to reset CO_2 levels, which increases operation costs (Ferentinos *et al.*, 2000).

Maintaining high CO_2 concentrations increasing ventilation rates produces a gradual rise in the system cost. In general, the algorithmic control performed by available programs and computers for climate control relates the CO_2 concentrations supplied by the window opening with the wind speed and physiological state of the crop (Heij and Schapendonk, 1984).

Schapendonk and Van Tilburg (1984) developed a simulation model to predict the dynamics of CO_2 fluctuations in a greenhouse cultivating cucumber at the stage of development with a leaf area index equal to 3. This model can be used to calculate the instantaneous assimilation of CO_2 by a crop as a function of its supply.

2.13. Management of climate control systems

All climate control systems require computer systems for their management because of the large number of variables and interactions that must be considered for their correct management. Thus, the equipment mentioned above involves the installation of sensors capable of measuring different climatic variables, including temperature, absolute or relative humidity, incident solar radiation, CO_2 concentration, and the speed and direction of wind. All these data are recorded and can be represented graphically by a computer, which also verifies control measures introduced by the user and sends relevant signals that adjust or stop the climate control equipment.

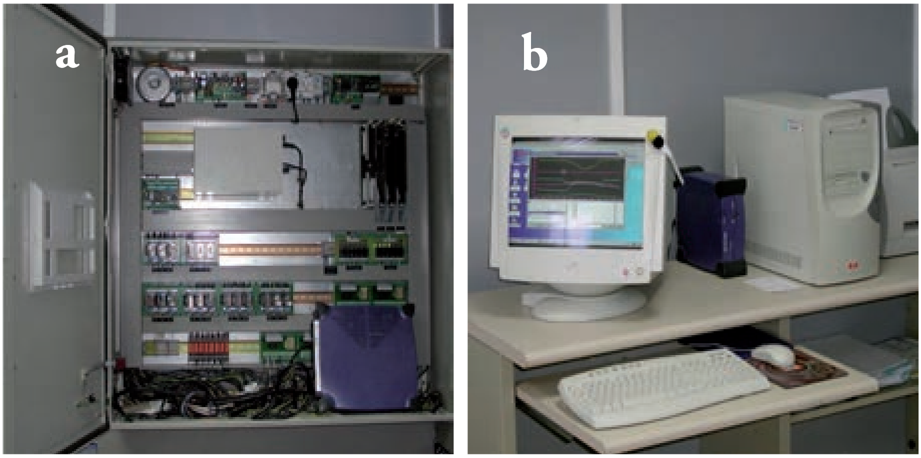
In traditional greenhouses, such as the 'raspa y amagado' type, small programmable controllers are used that regulate, for example, the opening and closing of windows or the operation of exhaust fans according to temperature and moisture (Figure 114).

Figure 114. Programmable controllers used in greenhouse climate control systems

More sophisticated facilities, such as modern multi-span or *Venlo* structure types, use microprocessors and computers with climate management software (Figure 115) that integrate all climate parameters with the actuators, including roof and side openings, forced ventilation, fog systems, heating, CO_2 injection, etc. These units record information and present it in graphical form, which allows for the detailed study of greenhouse operating conditions. These microprocessor-based systems maintain different climatic variables at fixed control levels and constitute true digital controllers (Davis and Hooper, 1991).

These systems can vary the set points temperature and humidity control based on other parameters, such as wind or solar radiation. Wind is one of the factors with the greatest influence on heat loss in greenhouses, and several studies have shown that the coefficient of heat loss is a linear function of wind speed (Bailey, 1980). Therefore, energy can be saved by reducing the temperature of the greenhouse when the wind speed is high and increasing it when the wind speed is low.

Figure 115. Greenhouse climate controller using a microprocessor (a) and a data-logging computer (b)



Several studies have shown that certain horticultural species, such as tomato (Hurd and Graves, 1984), pepper, lettuce (Hand and Hannah, 1978) and chrysanthemum (Langhans *et al.*, 1982), have the ability to integrate temperature. As a result, they respond to average temperatures, and fluctuations within a certain limit do not have a perceptible influence on growth or performance. This allows a reduction of heating costs without affecting yield because heating can be applied during periods that are more cost effective.

The entire environmental control process in greenhouses consists of a three-level control system with different time scales. The highest level corresponds to the largest time scale and is concerned with basic decisions on crop and production planning. The intermediate level corresponds to a time scale of one day to one week, and this level is related to the control of plant growth and development. At this level, dynamic optimisation is applied to determine the reference values of weather. The last level corresponds to a time scale of minutes and is related to implementing the optimised conditions through the climate controller of the greenhouse.

Another consideration in the management of climate control systems is the information entry by the farmer. At the simplest level, such information includes net profits, whereas at a more complex level, such information includes factors that affect crop development. Crop models cannot include all the factors that influence crop yield, such as the effects of pests and diseases or occurrence of abnormal weather conditions that create serious stress in crops.

Conflicts between short-term optimisation and the long-term capacity of the crop may also arise. The application of crop growth models does not eliminate differences in potential yield and quality among different farmers. Therefore, the farmer should be consulted on long-term crop-control decisions.

2.14. Fertigation equipment

With the introduction of irrigation systems in almost all the greenhouses in Almería (Figure 116), fertilisation is now conducted through the irrigation water. Thus, the required amount of fertiliser has been reduced, as fertilisation by this route has improved nutrient distribution and assimilation by the plant.

Different fertigation equipment exists depending on the injection system used to introduce fertilisers into the irrigation network.

Figure 116. Localised irrigation in a sand-plot tomato crop

2.14.1. Fertiliser tanks

Fertiliser tanks are the simplest systems for introducing fertilisers and were the first systems used in Almería greenhouses. These systems consist of an impermeable tank that is connected to the irrigation network and used to dissolve the fertiliser (Figure 117).

Figure 117. Fertiliser tank connected in parallel to the irrigation network

To introduce the fertiliser solution into the network, a valve is installed that can be gradually closed until a differential pressure at the inlet and outlet of the tank is achieved so that part of the flow can be diverted through the tank. This system is the most economical, although it may cause differences in plant growth because of a lack of uniform distribution since the injection into the network is not performed proportionally to the irrigation flow.

2.14.2. Direct-aspiration pump tanks

In these systems, a tank in which the fertilisers are dissolved is connected to aspiration pipes of the main pump of the irrigation network (Figure 118). The suction created by the pump draws the water and fertiliser mixture from the tank, and a valve and a flowmeter regulate the supply of fertiliser solution to the irrigation network, which is dependent on the operating pressure of the pump. This is a simple system that can be easily incorporated to the irrigation network when the latter is fed from a pond below the level of the pump.

Figure 118. Fertigation system using a direct aspiration pump tan

2.14.3. Venturi suction equipment

This equipment is based on the principle of conservation of mechanical energy of fluids, by which the increased speed of the fluid produced at a narrow point of the pipe generates a pressure loss at that point. These systems consist of pipes parallel to the main irrigation network in which water circulates through a narrowing that induces a large drop in pressure by the Venturi effect. A small bypass duct from the fertiliser tank is connected at this point, so that when the pressure at the Venturi unit drops, the fertiliser solution is injected by suction into the main circuit.

This system usually consists of three or four different nutrient deposits connected to separate Venturi units (Figure 119). It allows for the individual application of primary nutrients (N-P-K), calcium, microelements and nitric acid, the latter being used for pH adjustment and cleaning of the irrigation network. Thus, Venturi suction equipment allows for greater control of fertilisation.

Figure 119. Detail of the Venturi injectors on a fertigation system

2.14.4. Injection-based fertiliser dispensers

In these systems, a fairly accurate fertilisation dosage is achieved through the injection of a nutrient solution into the network. The liquid in the fertiliser tank is injected into the main network at a greater pressure than that of the irrigation water through an auxiliary pump. These dispensers are composed of piston or membrane pumps, and they can be operated electrically or mechanically. Hydraulic feeders powered by the pressure irrigation network can be used in certain cases. These systems are equipped with a control system at the level of the fertiliser tanks that prevents the injection of air into the network. In addition, tanks can be equipped with an agitation system to maintain a constant concentration of the dissolved solution and prevent precipitation of the fertilisers.

2.14.5. Automatic equipment

Modern fertigation facilities (Figure 120) are controlled by computers or automated systems, and the supply of nutrients is conducted according to the needs of the crop. These systems optimise the absorption of nutrients by the plant by maintaining a slightly acidic pH level in the irrigation water (between 5.5 and 6.5) through the application of corrective acids (nitric, sulphuric, phosphoric, etc.) to increase nutrient solubility.

Another factor that must be controlled in the greenhouses of Almería is the salinity of the water, which entails measuring the electrical conductivity (EC) in proportion to the concentration of the irrigation solution, including the fertilisers.

The EC, pH and temperature of the nutrient solution are measured using sensors that require corrected conductivity values. This automatic equipment uses both Venturi systems (Figure 121) and injection pumps. In both cases, injection is controlled by solenoid valves that open when they receive an electrical impulse from the automated controller. Injection occurs by electrical pulses on the order of milliseconds so that the valve is opened successively until the EC and pH control parameters conform to the desired value.

Figure 120. Automated fertigation facility

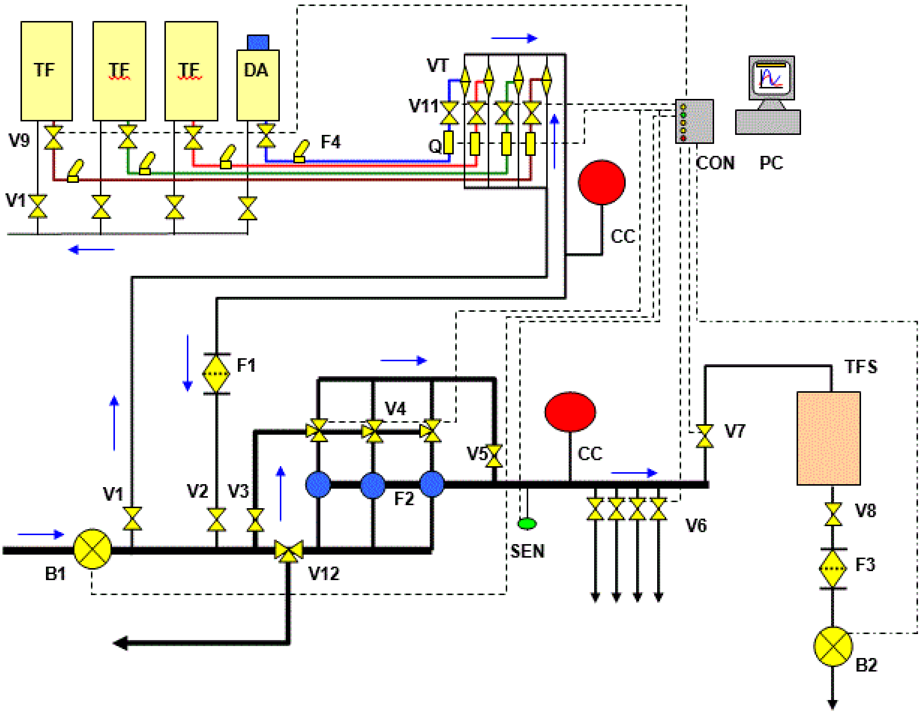
Figure 121. Automated fertigation system with Venturi injectors

In certain cases, membrane pumps are used to inject the fertiliser solution into a closed circuit, where «T» solenoid shunt valves send the water to an auxiliary mixing tank and a second electric pump injects the mixture at increased pressure into the main network.

In small agricultural holdings with a high uniformity of irrigation sectors, automatic equipment can be installed in series so that all the water is passed through the equipment. Such systems require an intermediate tank to mix the fertilisation solution with the irrigation water. A pump at the outlet of this tank provides flow and pressure in the irrigation network.

In general, computers are installed in parallel with the irrigation network, and injection occurs with a portion of the water (Figure 122). To produce a good mix of concentrated fertiliser solution with the rest of the water, injection is performed at a point on the network before the filtering head so that the turbulent flow produced during the filtering process uniformly mixes the irrigation water.

Figure 122. Diagram of automatic fertigation equipment



Q	Flowmeters	V1	Injection group inlet valve
VT	Venturi injector	V2	Injection group outlet valve
TF	Fertiliser tanks	V3	Filter cleaning valve
DA	Acid tanks	V4	Filter group solenoid valve
TFS	Secondary fertigation tank	V5	Filter group outlet valve
CC	Compensation drum	V6	Irrigation sector solenoid valve
B1	Impulse pump	V7	SFT feed valve
B2	Impulse pump for fertilisation	V8	SFT outlet valve
F1	Injection system filter	V9	FT outlet valve
F2	Filtering group	V10	FT purge valve
F3	Outlet filter TFS	V11	Injection solenoid valves
F4	Outlet filter of the fertilisers	V12	Filter group purge valve
CON	Automatic control	SEN	CE, pH and temperature sensors
PC	Computer controller		

2.14.6. Fertigation control

Fertilisation is generally controlled by determining the percentage of injection required for each fertiliser based on the volume of the nutrient solution and the total volume of irrigation water. Automatic equipment enables secondary control using EC measurements throughout the fertilisation process. pH regulation is conducted independently of fertilisation to maintain the desired levels of acidity.

In other cases, automatic equipment (Figure 123) injects the nutrient solution according to the EC and pH readings so that they are maintained within the desired range; however, the proportion of different nutrients that constitute the fertiliser remains constant. A secondary control can be used to determine the volume of irrigation water as well as the volume of fertiliser used at each moment.

The water supply can be adjusted according to the time required to supply an estimated volume of fertiliser or the requirements of the plant (irrigation on demand). Sand-plot crops usually use scheduled irrigation in which the farmer calculates the irrigation time required each day based on the physiological state and phenological stage of the plant and climate.

Irrigation on demand can be determined using climatic sensors that establish the critical values of temperature or humidity at which irrigation is necessary. Tensiometers (Figure 124) can also be used to determine irrigation requirements, although such systems require correct positioning of the tensiometers with respect to the rooting zone of plants and a good distribution inside the greenhouse to avoid errors caused by heterogeneity of the soil.

Figure 123. Electronic equipment of an automatic fertigation controller and a control panel with lights for the indication of operating systems

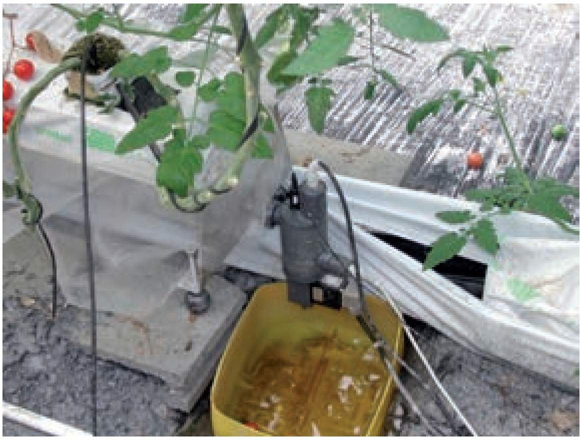
Figure 124. Tensiometers used for irrigation control in greenhouses

With automatic fertigation equipment, a series of programs can be selected for scheduled irrigation and irrigation on demand. For scheduled irrigation, parameters such as the irrigation duration and sectors, pH, EC and fertiliser percentages can be pre-determined. Irrigation programming can be performed according to the start and end time, number of irrigations per day, or time period between irrigations.

Irrigation on demand is generally limited to greenhouses with hydroponic crops where the exact needs of the plants can be determined using pH and EC sensors at the substrate. In this process, two bags of substrate are placed on a tray where drainage water accumulates, and the plant roots come into contact with the nutrient solution through porous fabric panels placed in the bottom of the tray. When climatic conditions force the plants to consume more water, the roots absorb part of the water from the tray, thus resulting in a drop of the water level in the tray (Figure 125). This decline can be detected by an electrode that sends a signal to the irrigation equipment, which activates the fertigation process.

A second more complex system consists of collecting drainage from the two bags on the tray and determining their volume. Irrigation occurs according to a minimum level of accumulated radiation (measured with a sensor), which is modified according to the percentage of desired drainage and decreased if the actual drainage exceeds the desired drainage.

Figure 125. pH and EC sensors used for irrigation control in greenhouses



2.15. Desalinisation equipment

As a complement to fertigation equipment, farmers have installed desalination systems that use reverse osmosis techniques (Figure 126) and allow well water with high salt content and high electrical conductivity to be used. In addition, these systems can provide water to evaporative cooling systems.

Figure 126. Desalination equipment for well water for use in greenhouse irrigation

The irrigation water used by the fertigation system is mixed with desalinated water pumped directly from the well, and the concentrations in the mixture vary according to the EC needs of each crop. For example, the organoleptic qualities of the fruit of certain varieties of tomato are improved with higher salt contents in the irrigation water.

2.16. Machinery used in greenhouses

Almería greenhouses utilise machinery to accomplish three types of tasks: maintenance and cleaning of the sanded plots; support for manual tasks of plant manipulation (trellising, topping, pruning, etc.) and harvesting; and application of phytosanitary treatments.

2.16.1. Mechanisation of horticultural labour

Although certain greenhouses have a high degree of automation and mechanisation, these facilities only represent a small proportion of the greenhouse agricultural landscape, in which most of the holdings only have one or two machines. Thus, few greenhouses have their own tractors (Valera *et al.*, 2002a), which is the most important piece of equipment of any agricultural holding.

Tractors perform multiple tasks within greenhouse horticultural holdings by using different tools or complementary equipment. In greenhouses, tractors of medium power from 30 to 60 HP (22-44 kW) with four-wheel traction are used, and they are articulated to increase manoeuvrability (Figure 127).

Tractors are used to perform ground manipulation during ploughing work (Figure 127) as well as broadcasting and banding, which wholly or partly renew the layer of organic material below the sand. In addition, tractors are used to remove crop remains through fork loaders powered by remote outlets on the hydraulic system of the tractor, and small shovels can also be used for these types of cleaning tasks (Figure 128).

Another important use of tractors is to transport boxes of fruit with the help of a trailer. Similarly, many farmers attach phytosanitary treatment equipment to tractors.

Figure 127. Four-wheel-drive articulated tractors used in greenhouses for the preparation of sand plots (a) and maintenance by ploughing (b)

Tractors in greenhouses experience problems because most traditional flat-type or 'raspa y amagado' type greenhouses have distances between supports of 2 to 4 m, which hinders their manoeuvrability. In addition, small distances between crop lines (0.7-1 m) hinder the use of tractors within the growing area. Moreover, many greenhouses do not have sufficiently wide and well-distributed interior corridors to facilitate the transit of machinery.

Figure 128. Shovel loader used in greenhouses for waste management

The structures that are currently built for Almería-type greenhouses and both types of metallic profile structures (multi-span and *Venlo*) facilitate the introduction of machinery by increasing the distance between supports up to 6-9 m.

In more sophisticated greenhouses in which soilless crops are now standard, soil maintenance is unnecessary, so the tractor has been replaced by a series of machines more suitable for industry than the farms, such as forklifts (Figure 129a) and pallet jacks (Figure 129b), which allow fast and comfortable transport of pallets. Such operations are possible in greenhouses equipped with concrete-floor corridors and storage facilities that allow for the operation of such equipment.

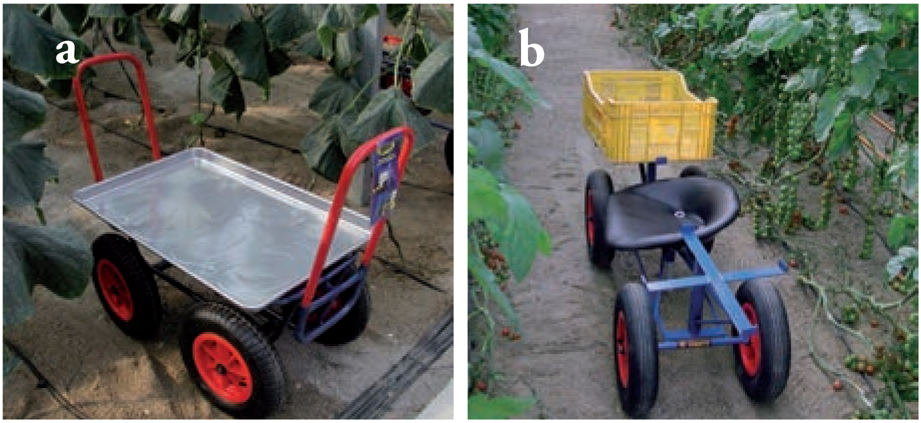
Figure 129. Forklift (a) and pallet jack (b) used for loading work and transport within greenhouses and nurseries

The horticultural works of transplantation, pruning, trellising, topping, piecework, defoliating, thinning, weeding and harvesting are still conducted manually in all greenhouses. However, mobile lift systems (mobile scaffolding) are used as an aid for certain tasks, and they allow operators to move between the crop lines by varying the platform height depending on the height of the plant zone to be manipulated. These systems are available for their use over heating rails (Figure 130a) or directly on the ground supported by pneumatic wheels (Figure 130b).

Wheeled carts are also widely used in greenhouses for transportation of harvesting boxes between the crop lines. There are carts that allow operators to move boxes filled with fruit (Figure 131a) as well as those that provide ergonomic support to the operator during the harvesting process (Figure 131b).

Figure 130. Lifting platforms for operators supported on heating rails (a) and on the ground (b)

Figure 131. Carts for the transport of boxes between crop lines (a) and for transport and operator support (b)



Blowing machines can be used to assist in the natural process of air pollination, which is impeded in greenhouse crops by the airtightness of the structure. This equipment is equipped with a small fan that generates a blast of air from a cannon that can be guided by the operator into the areas of the crop where the flowers are found (Figure 132).

Figure 132. Blowing machine to facilitate air pollination in a greenhouse tomato crop

On farms with a high degree of automation, electronic data storage systems may be installed (Figure 133). These systems allow operators to introduce data corresponding to the aisles or rows of plants in which they have been working, type of work performed, and operator code. This information can then be collected onto a personal computer for the control of tasks conducted in the greenhouse and statistical processing of data for performance evaluations of each worker.

To facilitate fruit classification, small calibrating machines that separate the fruit according to size can be installed directly inside the greenhouse. Usually, unclassified fruit is brought to handling centres for sorting, although certain farms have small sorting machines that allow for direct sales from the greenhouses, thus generating higher profits for the farmer. These machines are useful and employed in other countries, such as Holland, although they are not comparable with the large equipment installed in the handling centres of Almería that have high operating capacities of up to 20,000 kg h^{-1} per processing line and can wash the product; classify it by size, weight and colour; and distribute it in plastic bags.

Figure 133. Electronic data storage system used to control time spent on field work

2.16.2. Machinery for the application of phytosanitary products

In greenhouses, the work that lends itself most easily to mechanisation is undoubtedly the implementation of phytosanitary or phytomedicinal treatments. Thus, a variety of machines are used that differ both in their degree of sophistication and in their operation and degree of mobility. The different types of equipment used in greenhouses are classified as follows:

A. **Stationary projected jet systems**.

Fixed networks of hydraulic spraying with:

a) Manual application spray guns.
b) Moveable horizontal bars.
c) Vertical bars on manually powered carts.
d) Vertical bars on carts on rails.

B. Stationary transported jet systems.

Networks of hydro-pneumatic fog systems.

Fixed hydro-pneumatic fog systems.

Fixed centrifugal-pneumatic sprayers.

C. Mobile projected jet systems.

Hydraulic sprayers:

a) Manual transport in backpack.
b) Semi-automatic transport in mobile carts.
c) Self-propelled vehicles.
d) Attached to a tractor.

D. Mobile transported jet systems.

Hydro-pneumatic atomisers:

a) Attached to a tractor.
b) Manual transport.

E. Pulverising machines attached to a tractor.

These various machines differ according to their mobility and the way they generate liquid drops for phytosanitary treatment (Table 10). Hydraulic spraying produces small-sized droplets that force the treatment fluid at high pressure through a nozzle with a small diameter opening.

Pneumatic spray systems for the application of plant protection products are based on the collision effect of airflow at high speed, which pulls the treatment fluid in the direction of the airflow and produces a type of fog that can permeate the entire crop surface. In this equipment, the speed of the airflow driver is increased to fragment the liquid into small droplets (< 50 µm) without requiring pre-spray through a nozzle, which occurs in the hydro-pneumatic sprayers. By narrowing the outlet of the supply line of the treatment liquid and increasing the speed of the airflow, suction is produced by the Venturi effect.

Table 10. Operating principles of the various phytosanitary treatment spray applications

Pulverisation	Equipment	Drop formation	Propulsion
Hydraulic	Pulveriser	Liquid pressure	Pump
Centrifugal	Centrifugal pulveriser	Centrifugal force	Rotating disc
Pneumatic	Fogger	Air flow	Fan
Hydro-pneumatic	Sprayer	Liquid pressure and air flow	Pump and fan
Centrifugal-pneumatic	Centrifugal sprayer	Centrifugal force and air flow	Disc and fan

In hydro-pneumatic sprayers, the liquid is sprayed in tiny droplets through the nozzles and driven by a hydraulic pump, and the liquid subsequently breaks into smaller sizes through collision with high-speed air generated by a fan or turbine.

A. Stationary projected-jet systems

Most of the Almería greenhouses are equipped with a fixed system for phytosanitary treatments (fixed hydraulic spray networks). These networks consist of projected jet hydraulic sprayers, where spraying is conducted by pressure applied to the treatment liquid as it is driven by a pump.

The passage of pressurised fluid through the nozzle of the application spray guns leads to a spray of droplets, and the size and distribution of the droplets depend on the operating pressure and nozzle characteristics. These systems are valid for all types of treatments, so they are the most frequently used in Almería. They consist of a tank, pump, distribution network and application spray guns or bars.

The tank (Figure 134) is the container where the treatment is mixed. This unit should consist of an absorption chamber for the pump that guarantees the pumping of liquid at all times without being interrupted by the agitation of the mixture.

Figure 134. Tanks for phytosanitary treatments with a jet agitation system

A drain valve is required at the lowest point to allow for total cleaning after each treatment. The most suitable tanks are those constructed of PP because they prevent residue accumulation on the walls and are resistant to chemical corrosion.

Coupled to the tank is an agitator that can be mechanically operated through movement from the absorption pump engine or an auxiliary engine, or it can be hydraulically operated when the movement of the fluid in the network is utilised to generate a current inside the tank (Figure 134).

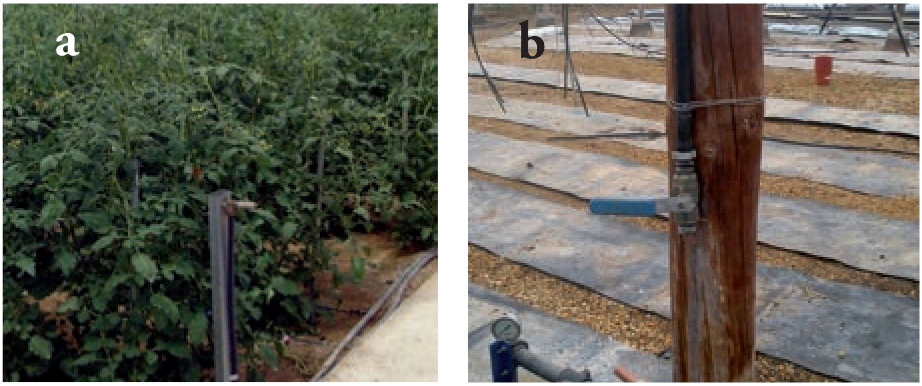
The pump is the key element that provides for correct system functioning. Pumps used for spraying equipment are generally of three types: piston pumps, which provide greater pressures of 40-50 bar; membrane pumps; and piston-membrane pumps, which provide lower pressures of approximately 10-25 bar.

It is important that these systems have an expansion vessel or compensation tank, which buffers the de-pressurisation that occurs in the lower chamber of the piston or membrane. Flow regulation occurs by maintaining constant pressure in the distribution network. Special attention should be paid to the status of the spray guns and their operating pressure, which must be the same for all the spray guns to ensure uniformity of the treatment.

Figure 135. Piston-membrane drive pumps powered by electric motors (a) and an internal-combustion diesel motor for operating a pump (b)

The distribution network generally consists of a PE primary pipe, which is placed parallel to the corridors. Connection points with stopcocks (Figure 136) that engage the secondary hoses or pipes that have treatment spray guns at the end are placed along the length of the pipe. The network consists of auxiliary elements such as gauges, which control the operating pressure at the different points of the network; output and input filters for the pump; and a pressure regulator in the return fluid of the tank that ensures a constant pressure in the network. Thus, a constant flow of treatment and good uniformity in the application is obtained from the network.

Figure 136. Connections for treatment hoses on the ground (a) and attached (b)



Fixed networks of hydraulic spraying

a) Manual application spray guns

Spray guns for manual application consist of an aperture system that controls the passage of liquid and one or several spraying nozzles (Figure 137) that distribute the liquid when it reaches a certain pressure are used in greenhouses. The nozzles should be checked often and cleaned or replaced when required.

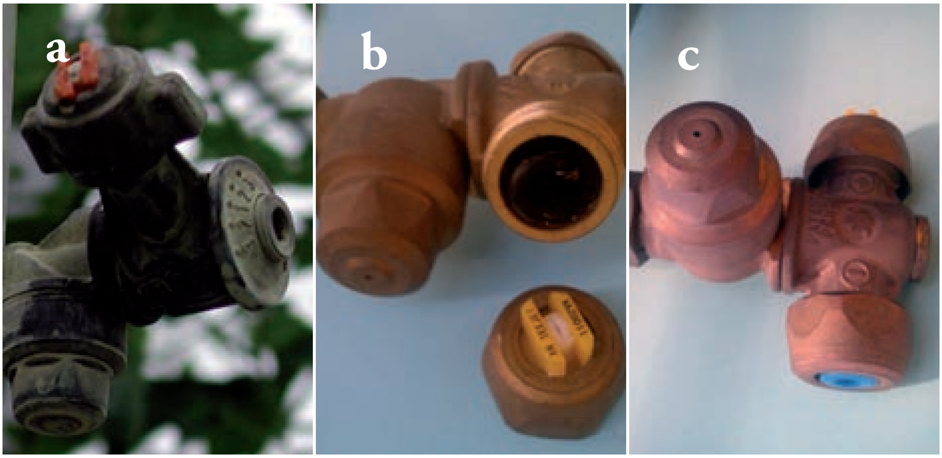
Figure 137. Spray guns for the application of phytosanitary treatments connected to a fixed network with three nozzles (a), two nozzles (b), and a single nozzle (c)

Spray guns are normally equipped with turbulence nozzles that produce a conical projection with an aperture angle between 50 and 80^0 and a small drop size ranging between 200 and 400 µm. Operating flows of 2-7 L min^{-1} for pressures of 10 to 50 bar are used. These nozzles consist of a body, propeller, turbulence chamber, calibrated orifice, filter and locking nut, and they are appropriate for both fungicide and insecticide treatments.

When machines are used with vertical treatment bars connected to various nozzles, the flat jet spray on the outside is usually used for direct spraying on the crop lines (Figure 137a and b), and the cone on the inside is used for creating a fine mist (Figure 137c).

Flat-jet spray nozzles usually have an aperture angle between 80 and 110^0, separation in the bar from 50 to 75 cm, and operating pressures of 1 to 4 bar. The amount of supplied water is reduced because of the greater number of nozzles (between 10 and 20), which have values between 0.5 and 2 L min^{-1}. Nozzles with full cones include a disc of different materials (ceramic, hardened stainless steel, stainless steel and polymer) that is configured based on the required level of resistance with a calibrated orifice between 0.8 and 4 mm in diameter, which produces cones with an angle of aperture of 20 to 65^0 for 1 to 20 bar operating pressures.

Figure 138. Flat-spray nozzles (a) and (b), and nozzle with full cone with disc (c)



The main drawback of spraying networks with manual spray guns is the resulting high exposure of workers to phytosanitary products during application treatments. In addition, they require a greater application volume and have low application efficiency because of high losses from deposition on the soil (Sánchez-Hermosilla *et al.*, 2013). However, these spray guns continue to be the standard method for phytosanitary treatments, which are increasingly reduced in the current system of integrated pest control, because of their ability to control the plant zones where application takes place in comparison to the other alternatives.

b) Mobile horizontal treatment bars

Some nurseries employ fixed spraying networks connected to mobile horizontal bars hung from the structure of the greenhouse, which move automatically on rails above the plants on growing tables (Figure 139). This system has two significant advantages over spray guns: a high degree of dose homogeneity and the possibility of automated treatment applications that eliminate the need for workers inside the greenhouse during treatment.

Figure 139. Mobile horizontal treatment bar used for phytosanitation treatments in a nursery

c) Vertical bars on manually operated carts

Another alternative to the use of spray guns for manual applications is the use of vertical bars placed on carts pushed by an operator through the aisles between crops (Figure 140a). The main advantage of this system is the speed of treatment, which utilises bars that contain various nozzles for the homogeneous application of phytosanitary products to the lines of plants located on either side of the aisle and above and below the aisle. However, these systems require an operator (Figure 140b), whose exposure to the cloud of phytosanitary droplets is even higher than that of the traditional spray-gun method.

Figure 140. Vertical bar on a cart (a), and demonstration of its manual operation applying only water (b)

d) Vertical bars on carts on rails

There are also self-propelled electrically powered spraying vehicles that move on rails using the pipes of the heating system. These vehicles may or may not require an operator (Figure 141), and only the latter reduces the toxification risk and decreases labour costs. A controller, however, is required to manage the movement of the machine, which is programmed using a console of input commands (Figure 141b). This equipment is restricted to highly technically advanced holdings with multi-span or *Venlo* greenhouses because of the need of heating pipes as rails and its higher cost compared with manual systems.

Figure 141. Self-propelled electric carts with vertical treatment bars: operator controlled, demonstrating the application of only water (a), and automated (b)

B. Stationary transported jet systems

An alternative to stationary hydraulic spraying systems is to use atomisation equipment that use pneumatically driven nozzles that are distributed inside the greenhouse through a fixed distribution network, or to use ventilation equipment that generates large air jets for the transport of phytosanitary treatment droplets.

Networks of fixed hydro-pneumatic fog systems

Phytosanitary treatment systems using networks of hydro-pneumatic fog systems are similar to the equipment used for cooling by evaporation of water (section 2.8). In fact, it is common for farmers to use the system with a double function: as a fog system for water cooling and for phytosanitary treatments.

The main advantage of the fixed treatment equipment is that it allows for the application of phytosanitary products when the greenhouse is closed and empty, which eliminates the risk of toxification to the workers and prevents the escape of insects during treatment. In addition, these systems permit treatments at dusk, which decreases the necessary dosage because of reduced losses through evaporation.

However, static systems cannot discriminate between different plants according to their health status, and certain parts of the plant are difficult to reach, such as the lower section of the stem and underside of the leaves on tall and well-developed crops with narrow spacing and considerable leaf mass. Other drawbacks include the production of a heterogeneous distribution with higher concentrations in the vicinity of the emitting nozzles (Sánchez-Hermosilla *et al.*, 2012), reduced deposition on crop leaves, evaporation losses and increased water costs compared with manual hydraulic spray guns (Sánchez-Hermosilla *et al.*, 2013).

These systems use powerful compression equipment that distributes air at high pressure (between 6 and 7 bar) throughout the entire greenhouse. Using a secondary network of parallel pipes, the treatment is distributed from mixing tanks (Figure 142) through low pressure pumps (2-3 bar).

Figure 142. Tanks with agitator system and impulsion pumps of a phytosanitary treatment system using a stationary network of fog systems

Application nozzles that receive the treatment fluid through a micro-pipe are placed along the pipes of compressed air, which produce a jet stream of drops carried by the flow of air (Figure 143).

Figure 143. Stream of air and treatment drops generated by a fogging nozzle

Fixed hydro-pneumatic fog systems

This system consists of ventilation equipment (Figure 144) that circulates air (flow approximately 5 $m^3 h^{-1}$) inside the greenhouse, creating a continuous flow of air that transports droplets generated by one or more spray nozzles placed in the centre (one nozzle) or periphery (multiple nozzles) in front of the air outlet of the fan.

The treatment liquid is injected through nozzles (application flow of approximately 2-3 L h^{-1}), where it is mixed with air to produce a fog of microdroplets (5-20 µm). This system can distribute the treatment in the form of a fog that permeates the crop and reduces the risk of excessive product deposition that can burn the leaves or fruits.

The fans for these systems are hung from the structure of the greenhouse and receive 5 L of treatment fluid through individual tanks (Figure 144) or a network of pipes that distribute the fluid to different apparatuses from a general tank. The pressure of the treatment fluid fed through a network of pipes is achieved by a single pump that provides operating pressures between 1 and 5 MPa. When small tanks (5 or 15 L) are used, pressure is achieved by small individual dry piston compressors (no oil) that operate at pressures from 0. 5-0.8 MPa.

Figure 144. Static jet-transported hydro-pneumatic sprayer of ultra-low volume

These systems are often marketed as ultra-low volume systems in reference to the reduced volume of the treatment application compared with that of spraying equipment, which is caused by the direct injection of treatment product into the air stream. Thus, the product does not have to be mixed with water. Spraying equipment is called fogging equipment because it generates small drops (Table 11) and creates some amount of fog inside the greenhouse, although this is a misnomer because the name is unrelated to the operating principle.

Table 11. Classification of spray drop size according to the British Crop Protection Council

Volume of drop	Very fine	Fine	Medium	Thick	Very thick
Dv 0,1 (10 %*)	< 55 µm	55-94 µm	95-164 µm	165-225 µm	> 225 µm
Dv 0,5 (50 %*)	< 119 µm	119-216 µm	217-353 µm	354-464 µm	> 464 µm
Dv 0,9 (90 %*)	< 204 µm	204-369 µm	370-598 µm	599-789 µm	> 789 µm

* *Percentage of the accumulated volume of drops.*

Source: Doble *et al.* (1985).

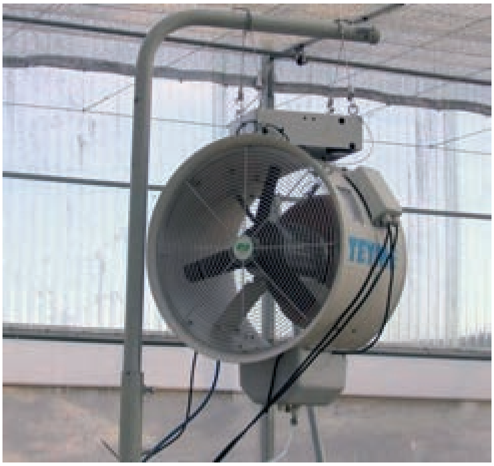
This method enables phytosanitary treatments to be conducted in an automated fashion without the need for operators in the greenhouse, which eliminates risks to the workers. Treatments can be programmed so that they occur at dusk to avoid high daytime temperatures, thus increasing their effectiveness. However, it has the same drawbacks as hydro-pneumatic fog systems with the addition of a more heterogeneous treatment distribution.

Fixed centrifugal-pneumatic sprayers

Fixed centrifugal-pneumatic spraying systems for treatment applications (Figure 145) consist of a fan with a rotating disc located at the back, where a jet of water is introduced. The water stream subsequently ruptures in the form of small droplets that are transported by ventilated air flow and move over the plants at a height of approximately 15-35 m inside the greenhouse.

The application flows (approximately 10-40 L h^{-1}) are much larger than in the previous system but have a larger particle size (10-30 µm). Because of the higher treatment flow, the fluid is supplied through a central tank and a small distribution circuit.

Figure 145. Centrifugal-pneumatic transported-jet sprayer



C. Mobile jet-projected systems

In addition to the use of fixed systems, there are also mobile alternatives for phytosanitary treatment that consist of an individual tank, a drive system and the required elements for application (nozzles and/or fan).

Hydraulic sprayers

a) Backpack sprayers

For the application of localised treatments for certain crops, backpack sprayers are commonly used (Figure 146b), which hang on the back of the operator. These sprayers are equipped with 15-20 L tanks and a vacuum pump that can be operated manually.

Hand-operated pumps with pressures of 5-10 bar can be used, which provide application flow rates of 2-5 L min^{-1}. Distribution occurs through a treatment spear equipped with a nozzle at the end, with the spear composed of a body, filter and «mirror» to project an open fan-type jet that reaches amplitudes of 100-120º. The drop size achieved with these nozzles ranges between 400 and 1,000 µm.

b) Semi-autonomous mobile hydraulic sprayers

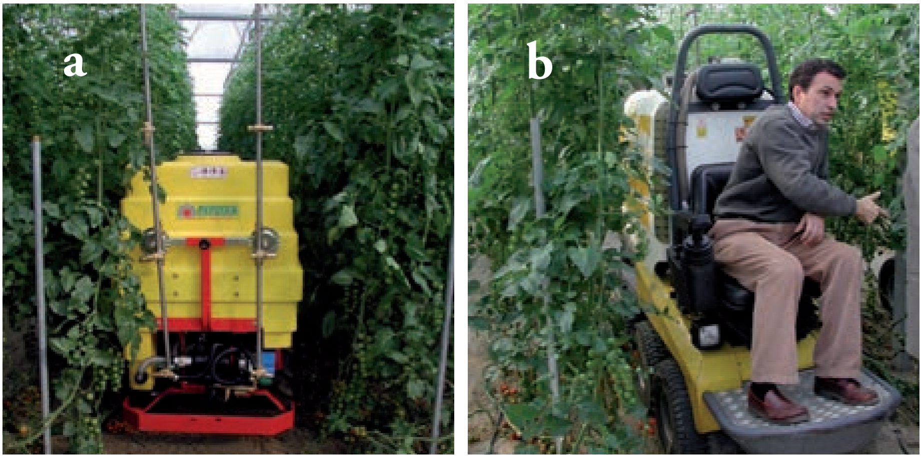
In older facilities that have a small surface and do not include fixed distribution networks of phytosanitary products, carts with tanks of approximately 100 L installed with a membrane pump can be used to drive liquid directly to a hose attached with a treatment gun (Figure 146a).

c) Self-propelled vehicles for hydraulic spraying

Self-propelled vehicles on pneumatic wheels are a recent alternative to hydraulic spraying through fixed network systems (Figure 147). These vehicles are designed to move through the aisles of sand-plot greenhouses without heating pipes between crop lines.

Figure 146. Mobile hydraulic sprayer (a) and backpack sprayer (b)

Figure 147. Self-propelled vehicles for hydraulic spraying: rear view of the treatment bar (a) and front view with driver seat (b)



This equipment is composed of an autonomous vehicle with an electric motor, a liquid treatment tank, a hydraulic pump drive, and two nozzle rack bars. In general, these systems allow adequate control of the advance speed and flow of treatment, which improves the treatment's effectiveness compared with that of fixed networks.

D. Mobile transported jet systems

Hydro-pneumatic atomisers

a) Attached to a tractor

Fog systems create a fog formed by tiny droplets of liquid (< 50 µm) that remain in suspension and are deposited slowly over the crop. These applications produce a toxic environment for parasites in the greenhouse.

Mobile fog cannons that are attached to three-point tractor hitches (Figure 148) can easily treat a greenhouse in a short period of time (achieves 1-2 yields ha h^{-1}). This system consists of a treatment mixing tank and a small pump that injects the liquid over the air jet produced by a radial-flow fan attached to the power take-off shaft of the tractor. When the liquid is injected at pressure over the air current flowing at high speed, the drops are fragmented into smaller units, which move a long distance through transport by the air.

Figure 148. Hydro-pneumatic sprayers suspended on a tractor

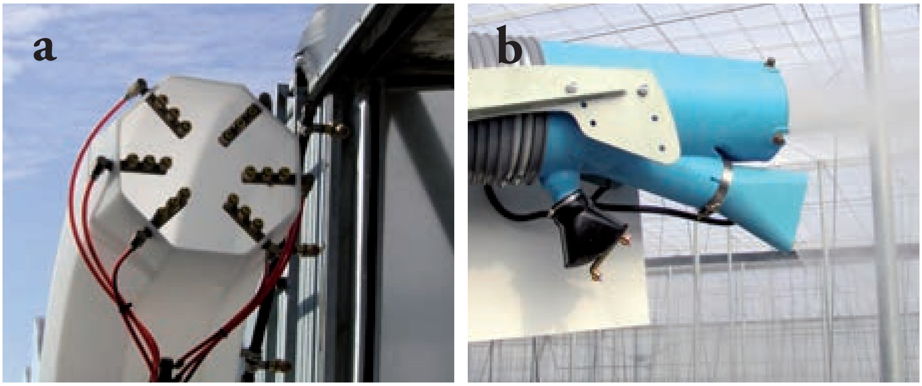
In this application system, it is important to the use proper protection, such as masks, goggles, gloves, and impermeable clothing, to avoid contact with the toxic cloud that is generated inside the greenhouse.

Treatments for crops that have not yet developed or have small leaf masses or for trailing crops, such as melon and watermelon, can be applied much more quickly using sprayers or fog systems attached to a tractor (Figure 149). In these systems, the tractor moves forward along the central corridors of the greenhouse, distributing the treatment over the entire crop. Such treatment requires the presence of at least one operator inside the greenhouse, and protection must be used to avoid contact with the toxic cloud that is generated. Historically, the awareness of individual protection methods was limited, which is reflected in the photograph in Figure 149.

Figure 149. Hydro-pneumatic sprayer performing a treatment

A drawback to these systems is the lack of uniformity in the treatment along the crop lines, with the areas closest to the central aisle where the tractor circulates receiving reduced depositions. To provide greater uniformity of treatment, this equipment has been updated to include a principal canon as well as two smaller diameter outputs oriented towards the plants closest to the equipment.

Figure 150. Detail of air outputs in hydro-pneumatic sprayers through a single output (a) or three outputs (b)



b) Manually adjustable

Manually adjustable atomisers (Figure 151) are mobile machines that consist of one or two fans with characteristics similar to stationary systems. However, instead of being «fixed» to the greenhouse structure, they are positioned on a wheeled cart on which a small treatment tank and compressor has been installed. Thus, the position and direction of application within the greenhouse can be modified.

Figure 151. Manually adjustable hydro-pneumatic sprayer

E. Pulverising machines attached to a tractor

Another method of applying phytosanitary products in dust formulas is through the use of pulveriser machines (Figure 152). This equipment uses the air flow generated by a fan to pick up the dust particles and distribute them over the crop.

Figure 152. Pulverisation machines attached to a tractor

2.17. Environmental impact of the greenhouse agriculture in Almería

In the current economic context, the efficiency of all production processes must be optimised. In the case of agriculture in general and greenhouse horticulture in particular, this implies reducing the ratio of the production costs with respect to their value upon sale of the harvest. At the same time, climate change must be addressed, and the environmental impact of different production activities must be reduced, which requires minimising energy and water use in all agricultural activities. Greenhouses constitute a production system that can use climate control systems that consume significant amounts of energy and water, such as evaporative heating or cooling systems, respectively. However, most of the greenhouses in Almería are based on the exclusive use of natural ventilation and whitewashing techniques as climate control systems.

Natural ventilation makes it possible to control the temperature, humidity and carbon dioxide concentration values inside a greenhouse. However, its operational capacity is limited by outdoor conditions because such ventilation is based on the renewal of interior air by exterior air, which is normally cooler (Molina-Aiz, 2010), less humid and has a constant concentration of CO_2. Similarly, whitewashing of the greenhouse cover reduces the infiltration of solar radiation into the greenhouse (Baille *et al.*, 2001), which, on the one hand, allows photosynthetic activity by crops and, on the other, provides energy that warms the plants, soil and air.

The greatest advantage of these two traditional techniques used in the greenhouses of Almería is that they do not require significant economic, energy, or water expenditures for their daily operation. The energy required to close and open greenhouse windows using electrical drives is only 0.02 MJ of energy per kg of tomatoes produced (for an average production of 19.0 kg m^{-2}), which constitutes a global warming potential (GWP) of 0.003 kg CO_2-eq/kg. This represents barely 0.5 % of the energy required in a plastic-covered multispan greenhouse in Almería (4 MJ kg^{-1} and 0.25 kg CO_2-eq/kg). In addition, the energy requirements per kilogram of tomatoes produced in a multi-span greenhouse of Almería with natural ventilation are the lowest of all greenhouses worldwide (Table 12). The global energy requirements of Almería's greenhouses are only comparable with the tunnel-type greenhouses of France (5.2 MJ kg^{-1}) or the *Venlo*-type greenhouses of Holland, provided they use cogeneration (5.0 MJ kg^{-1}). When the greenhouses from these more adverse climatic zones use conventional heating (without production of electrical energy), the associated Global Energy Requirements are on the order of 8-32 times greater than those of the non-heated greenhouses of Almería (Table 12).

For comparison purposes, the production of 1 kg of tomatoes in a glass greenhouse with a cogeneration system and artificial lighting in Holland requires a global energy demand of 11.9 MJ kg^{-1} (1.18 kg CO_2-eq/kg) to achieve a production output of 76.5 kg m^{-2} (van Zundert, 2012). Similarly, a heated multi-span greenhouse in France requires 31.6 MJ kg^{-1} (2.02 kg CO_2-eq/kg) to achieve a production of 44.0 kg m^{-2} (Boulard *et al.*, 2011).

Greenhouses in Almería are not only the most efficient with regard to their impact on global warming, but they have also demonstrated a positive impact on climate. Thus, the change in soil use from the natural land of Campo de Dalías , Campo de Níjar and Bajo Andarax to the whitewashed plastic greenhouses has drastically increased the reflection coefficient of direct sunlight, or albedo, by the earth's surface in these areas to 0.09 (Campra *et al.*, 2008). As a result, the net radiation at the surface has been reduced to 22.8 W m^{-2} in the southern area of the province of Almería, which has reduced the annual average temperature by 0.15ºC (Campra and Millstein, 2013). Therefore, the increase in albedo of the earth's surface caused by the reflection of greenhouses with whitewashed plastic covers has produced a significant offset of equivalent CO_2 emissions (CO_2-eq) that has reduced the GWP of tomato production from 0.303 to 0.168 kg CO_2-eq/kg (Muñoz *et al.*, 2010).

Table 12. Production values of tomatoes in different greenhouse types and countries

Country	Greenhouse type	P	GER	C	GWP	ADP	AAP	EUP	POP	W
Spain	Plastic multi-span	16,5	4,0		0,25	1,7	1,0	0,49	0,054	28,8
Holland	Glass *Venlo* with heating	56,5	30,9	31,0	1,93	14,7	3,2	0,85	0,215	14,1
Holland	Glass *Venlo* with cogeneration	56,5	5,0		0,84		1,3	1,85	0,241	
Holland	*Venlo* with cogeneration and lighting	76,5	11,9	39,0	1,18		1,6	1,97	0,092	
France	Tunnel with plastic cover	14,6	5,2		0,51		1,4		0,850	34,2
France	Plastic multi-span with heating	44,0	31,6		2,02		3,4		0,460	28,4
France	Glass with heating	44,0	31,3	85,3	2,01		3,4		0,447	28,4
Italy	Plastic	9,6	16,2		0,74		5,7	2,10	0,300	88,9
United Kingdom	Glass with heating		130,0		9,40	100	12,0	1,50		39,0
Switzerland	Glass with heating		42,0		3,30					
Canada	Plastic with heating	56,4	52,7	88,0	2,88					

P: production [kg/m^2].
GER, Global Energy Requirement [MJ/kg].
C, percentage of requirements related to heating [%].
GWP, Global Warming Potential [kg CO_2eq/kg].
ADP, Abiotic depletion [kg Sb eq/t].
AAP, Air acidification [kg SO_2 eq/t].
EUP, Eutrophication [kg PO_4^{-3} eq /t].
POP, Photochemical oxidation [kg C_2H_4 eq/t].
W, water requirements [m^3/t].

Source: [a] Torrellas *et al.* (2012); [b]Torrellas *et al.* (2013); [c]van Zundert (2012); [d]Boulard *et al.* (2011); [e]Cellura *et al.* (2012); [f]Willinas *et al.* (2006); [g]Carlsson-Kanyanma (1998); [h]Hendricks (2012).

In addition to assessing the energy consumption and global warming contributions of agricultural activities, it is important to recognise the influence of the greenhouse agricultural activity on local ecosystems and assess the environmental impacts. Several studies have conducted Life Cycle Assessments (LCAs) that focus on the study of environmental aspects and potential impacts throughout the life cycle of a product or activity. For horticultural activity in greenhouses, the following parameters tend to be used in such assessments (Boulard *et al.*, 2011; Cellura *et al.*, 2012; van Zundert, 2012; Torrellas *et al.*, 2013):

- Abiotic resource depletion (ADP), which is expressed as the consumption of antimony (Sb) per tonne of crop produced; this parameter is intended to measure the consumption of resources that compose the «greenhouse» ecosystem.
- Air Acidification (AAP), which measures air pollution expressed in kilograms of sulphate emissions (SO_2) into the atmosphere per tonne of crop produced.
- Eutrophication (EUP), which represents the nutrient enrichment of our ecosystem, which is quantified in kilograms of phosphates (PO_4^{-3}) per tonne of product harvested.
- Photochemical oxidation (POP), which is expressed in kilograms of ethylene emissions (C_2H_4) into the atmosphere per tonne of marketed product.

Table 12 shows values of these parameters for tomato crops in different greenhouse structures located in different countries. The set of parameters in the greenhouses of Almería produce less pollution compared with those of other countries. For POP, the values produced in Almería are up to 8 times less than those in other climatic zones. Even in water consumption per unit of product harvested, Almería has an efficient productive system compared with that of France, where the climate produces less evapotranspiration in the crop.

3. Procedure for obtaining field data

Field data were collected during the 2012/13 agricultural season through two methods. The first method consisted of a survey with 108 questions provided to 212 farmers, and the second method consisted of data obtained directly from 18 collaborating companies that market the products of these farmers who provided information about the past 6 seasons (from 2006/07 to 2011/12). Contact with the farmers was conducted through the collaborating companies except for a control group of 48 farmers, who were addressed directly to improve the sample validity. The following four agricultural regions of Almería with intensive greenhouse horticulture were studied: Campo de Dalías, Bajo Andarax, Campo de Níjar and Bajo Almanzora (Figure 153).

The sample area included 685 ha and represents 2.4 % of the total greenhouse area of Almería, which is quantified at 28,576 ha (CAPMA, 2013b).

The collaborating companies that participated in this study are as follows:

- Acrena, S.A.T.
- Agrupalmería, S.A.
- Agrupaejido, S.A.
- Cabasc, S.C.A.
- CASI, S.C.A.
- Casur, S.C.A.
- Coprohníjar, S.C.A.
- Costa de Níjar, S.A.T.
- Frutas Escobi, S.L.
- Hortamar, S.C.A.
- Hortasol, S.A.T.
- Hortofrutícola Costa de Almería, S.L.
- Hortofrutícola Mabe, S.A.T.
- Las Hortichuelas, S.A.T.
- Murgiverde, S.C.A.
- Parafruts, S.A.T.
- Parque Natural, S.C.A.
- Vicasol, S.C.A.

Figure 153. Sampled surface and surveys conducted in each region

3.1. Farmers' survey

At the time of formulation of the survey and with the goal of reflecting the hypotheses guiding our work, an advisory group was formed to collaborate with the study. This advisory group consisted of one or two farmers from the most representative agricultural regions of Almería, as well as lecturers and technicians related to the intensive horticulture sector. The main contribution of this group was in clarifying and guiding the 108 questions of the questionnaire and adapting the questions to the language, cultural level, age and socio-economic status of the subjects to be polled. In addition, this advisory group was used to suggest interview participants during the random stratified sampling phase.

Farmers were interviewed by two agricultural engineers with in-depth knowledge of the homogenous criteria used to complete the survey, so that potential sources of error were avoided. Because of the wide scope of the survey, each interview lasted approximately 45 minutes.

The objective of the study was explained to each interviewee, who was informed of the objective of the study and our intention to characterise the holding independent of the owner. A letter of confidentiality was also delivered to stress the statistical anonymity and explain that the data would only be used for aggregation without any individual references.

The questionnaire was organised into the following 10 sections that contain a variable number of both quantitative and qualitative responses (see Annex):

A. Personal data.
B. Crops.
C. Machinery.
D. Soil.
E. Auxiliary buildings and irrigation system.
F. Marketing.
G. Structure.
H. Climate control systems.
I. Cost-benefit analysis.
J. Labour.

The first section, «Personal data», consists of nine questions designed to obtain personal information, including the age of the farmer, years dedicated to agriculture, ownership status, geographical origin of the holder, education level of the holder, additional labour or business occupations, work performed prior to working in agriculture, and exact location of the surface of the farm.

The second seccion «Crops», includes questions to determine the methods of weed prevention, sowing and seedling preparation; frequency of foliar analysis; crops sown in the past three seasons, including their framework and yields; complementary and alternative methods of phytosanitary treatments; and methods of pollination and grafting.

The third section, «Machinery», includes questions to determine the existing machinery in the holding, including machinery used in the application of phytosanitary treatments, vehicles used for crop treatment, or machinery used to prepare the ground.

The fourth section, «Soil», includes questions to determine the soil type; use of soil analysis; types of disinfection; type and frequency of broadcasting as well as the related costs, quantity and wages; provision of humic acids; and if a conversion from sand plot to hydroponic holding (or vice versa) has been considered.

The fifth section, «Auxiliary Buildings and Irrigation Systems», includes questions to determine the most important features of the holding, such as information on the storage surface; irrigation hut and pond capacity; filters used; rainwater collection; irrigation system; water analysis, tensiometer use; water source, cost and quality; and fertilising method.

The sixth section, «Marketing», includes questions to determine where the products are sold, whether the same location is used, years of partnership in a cooperative, type of advising or counsel received, if the product is prepared before transport to the point of sale, and if the product is subject to a certification system or standard of good agricultural practices.

The seventh section, «Structure», is the largest section in terms of the number of questions, which are formulated to determine the characteristics of the greenhouse, including the structural elements, dimensions, corridors, window type and activation, double doors, insect screens, roofing material and replacement procedures.

The eighth section, «Climate control Systems», includes eight questions to determine the use of climatic controllers; measurement of parameters; use of thermal screens and shading meshes; use of forced ventilation systems and evaporative cooling techniques; use and type of heating, including fuels; energy-saving techniques; and other advanced systems, such as CO_2 injection, artificial lighting or cogeneration systems.

The ninth section, «Cost-Benefit Analysis», includes questions to determine the range of income and estimated costs incurred throughout the year or season; crops that provide higher net profits or require increased investment at the beginning of the season; and types of subsidies or entities that provide funding.

The tenth section, «Labour», includes questions to determine whether the workforce is self-employed or hired; number of workers and whether they are permanent or not; type of work for which contracted labour is hired; if there is any type of preferences in hiring; approximate wages dedicated to the holding; and if the owner's labour is included in those wages.

Finally, and no less revealing, a question is included on whether there are short-term plans for improvements on the holding, and if so, what type. The interviewees are also provided an opportunity to reflect on relevant facts in the latest seasons and state if they believe the study will improve the profitability of production infrastructures.

3.2. Sample validity

To determine the relationship between the structures of greenhouses in the province of Almería and their profitability, a questionnaire addressed to a representative sample of producers of vegetables in the province of Almería was designed. To this end, the municipalities with the highest density of greenhouses in Almería were identified. This sample is based on two studies that are the benchmarks for the assessment of greenhouse surface in the province of Almería, i.e. the «Cartography of Greenhouses on the Coast of Eastern Andalusia - 2012 Season Report», which was published by the Commission of Agriculture, Fishing and Environment of the Regional Government of Andalusia, and the study of the Foundation for Agricultural Research in the province of Almería (FIAPA, 2007), which assessed the detection of greenhouse surface in the province of Almería through Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) imagery.

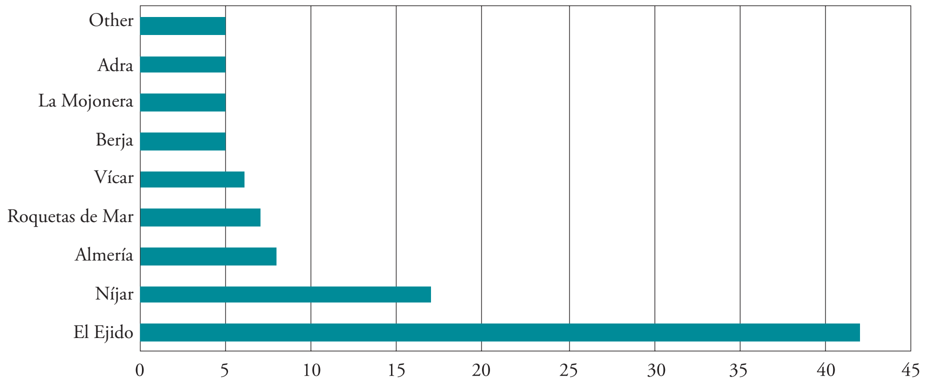
Table 13 indicates that new greenhouse surfaces increased by more than 2,500 ha in the province of Almería, with the most active installations occurring in Níjar. Thus, at the municipal level, it is necessary to recognise the importance of El Ejido, Almería (municipality) and Níjar as key territories for any study on the agri-food sector in Almería because these municipalities contain 67 % of the greenhouse surface of the province and house the offices of the main Almería-based companies that market agricultural products.

Table 13. Surface of greenhouses in the most representative municipalities of the province of Almería

		Greenhouse surface (ha)			
Region	**Municipality**	**FIAPA 2006/2007**	**Regional Government of Andalusia 2012**	**Variation (ha)**	**Considered surface (ha)**
Bajo Andarax	Alhama de Almería	30			30
	Almería	2.340	2.208	-132	2.208
	Benahadux	5	13	8	13
	Pechina	210	146	-64	146
	Viator	240	106	-134	106
Campo de Dalías	Adra	940	1.336	396	1.336
	Berja	1.070	1.476	406	1.476
	El Ejido	11.210	12.215	1.005	12.215
	La Mojonera	1.230	1.356	126	1.356
	Roquetas de Mar	1.810	1.899	89	1.899
	Vícar	1.790	1.834	44	1.834
Campo de Níjar	Níjar	3.850	4.941	1.091	4.941
Bajo Almanzora	Cuevas del Almanzora	185	234	49	234
	Pulpí	202	184	-18	184
Others regions	Other municipalities	871	598	-273	598
	Total	**25.983**	**28.546**	**2.563**	**28.576**

Source: CAPMA (2013b), FIAPA (Sanjuan-Estrada, 2007). Own elaboration.

Figure 154. Greenhouse surface by municipality. In percentage



Source: CAPMA (2013b).

At the municipal scale, the importance of the western municipalities of Almería, especially El Ejido, which contains 42 % of the greenhouse surface of the province, suggests focusing the majority of surveys in these locations. Campo de Níjar has a greater weight of greenhouse surface than Bajo Andarax relative to the provincial total corresponding to regions other than Campo de Dalías. However, to improve the representativeness of the sample and offer a more global view of the results, a study of several farms in the Bajo Almanzora region was incorporated, specifically in the Cuevas de Almanzora and Pulpí municipalities.

Sampling was conducted randomly in each of the designated municipalities during the phase of field work definition. The direct face-to-face interviews were conducted between April 1 and September 30, 2013 by applying two different methodologies of data collection. In the first phase, surveys were conducted with the collaborating companies, and in the second phase, individual surveys were conducted with members of the regional control group.

Table 14. Sample data: surface (ha) and number of farms surveyed

Region	Municipality	Surveyed surface	Nº surveys
Bajo Andarax (47,5 ha)	Alhama de Almería	2,1	2
	Almería	38,0	22
	Benahadux	2,6	1
	Pechina	1,6	1
	Viator	3,2	2
Campo de Dalías (369,9 ha)	Adra	9,0	4
	Berja	11,2	6
	El Ejido	210,9	65
	La Mojonera	40,7	15
	Roquetas de Mar	61,6	26
	Vícar	36,6	16
Campo de Níjar (212,8 ha)	Níjar	212,8	43
Bajo Almanzora (54,8 ha)	Cuevas del Almanzora	52,3	8
	Pulpí	2,5	1
	Total	**685,0**	**212**

Source: Own elaboration.

First phase. Non-probability sampling was performed by quota with the most representative of the 18 most important vendors of the province of Almería. The objective for this type of sampling was to ensure data collection for all representative crops of Almería's most important agricultural regions as well as from the most representative farmers of these companies.

Table 15. Sampling quota of the distributors of the province of Almería

Region	Location	Company	Surveyed
Bajo Andarax	El Alquián	Agrupalmería, S.A.	9
	La Cañada	CASI, S.C.A.	8
	Viator	Casur, S.C.A.	10
Campo de Dalías	Aguadulce	Las Hortichuelas, S.A.T.	9
		Parafruts, S.A.T.	9
	Balanegra	Cabasc, S.C.A	10
	El Ejido	Murgiverde, S.C.A.	8
	La Mojonera	Agrupaejido, S.A.	10
	La Puebla de Vícar	Vicasol, S.C.A.	8
	Las Norias de Daza	Frutas Escobi, S.L	8
	Roquetas de Mar	Hortofrutícola Costa de Almería S.L.	9
		Hortamar, S.C.A.	9
	Santa María del Águila	Acrena, S.A.T.	9
		Hortofrutícola Mabe, S.A.T.	10
Campo de Níjar	El Barranquete	Parque Natural, S.C.A.	8
	Ruescas	Hortasol, S.A.T.	6
	San Isidro	Coprohníjar, S.C.A.	10
		Costa de Níjar, S.A.T.	6
		Total sampling quota	**156**

Source: Own elaboration.

Second phase. Stratified sampling was conducted between the farmers and crops of the four regions with greatest greenhouse surface, including Campo de Dalías, Campo de Níjar, Bajo Andarax and Bajo Almanzor. Once the most representative crops for each zone were determined, farmers that had participated in this sample were randomly selected. Specifically, the farmers surveyed had been selected from the proposals received by the advisory group, which was formed in the design phase of the field study.

In summary, 212 surveys were conducted and distributed among the 14 surveyed municipalities. 156 surveys corresponded to sampling by quota and the remainder (56) corresponded to stratified random sampling.

Table 16. Representative sample

Region	Municipality	ha of greenhouses	Surveyed surface	p	q
Bajo Andarax	Alhama de Almería	30	2,1	0,07	0,93
	Almería	2.208	38,0	0,02	0,98
	Benahadux	13	2,6	0,20	0,80
	Pechina	146	1,6	0,01	0,99
	Viator	106	3,2	0,03	0,97
Campo de Dalías	Adra	1.336	9,0	0,01	0,99
	Berja	1.476	11,2	0,01	0,99
	El Ejido	12.215	210,9	0,02	0,98
	La Mojonera	1.356	40,7	0,03	0,97
	Roquetas de Mar	1.899	61,6	0,03	0,97
	Vícar	1.834	36,6	0,02	0,98
Campo de Níjar	Níjar	4.941	212,8	0,04	0,96
Bajo Almanzora	Cuevas del Almanzora	234	52,3	0,22	0,78
	Pulpí	184	2,5	0,01	0,99
Other region	Resto municipios	598	-	-	-
	Total	**28.576**	**685,0**	**0,02**	**0,98**

Source: Own elaboration.

Because of the size of the study population, 212 surveys were conducted and distributed among the 14 municipalities. A margin of error of ± 2.26 % and a confidence level of 95 % for the total sample were considered. Analytically, the sample size was obtained by applying the following statistical formula for the proportion of finite populations:

$$n = \frac{N}{1 + \left(\frac{d}{z_{\alpha/2}} \right)^2 \cdot \frac{(N-1)}{\overline{p} \cdot \overline{q}}}$$

Where (for the control population):

- «n» is the minimum sample size, i.e., 685 ha of surveyed greenhouses.
- «N» is the size of the control sample, which is considered to be 28,576 ha.
- «d» is the sample standard error, which was 1.132 % (± 2.26 % margin of error).
- «$Z_{\alpha/2}$» is the critical value at significance level α, which is 1.96 for a 95 % confidence level.
- «$\overline{p}$» is the average probability of an event occurring, such as surveying a greenhouse holding in any of the 14 municipalities considered.
- «$\overline{q}$» is the average probability of the opposite event occurring.

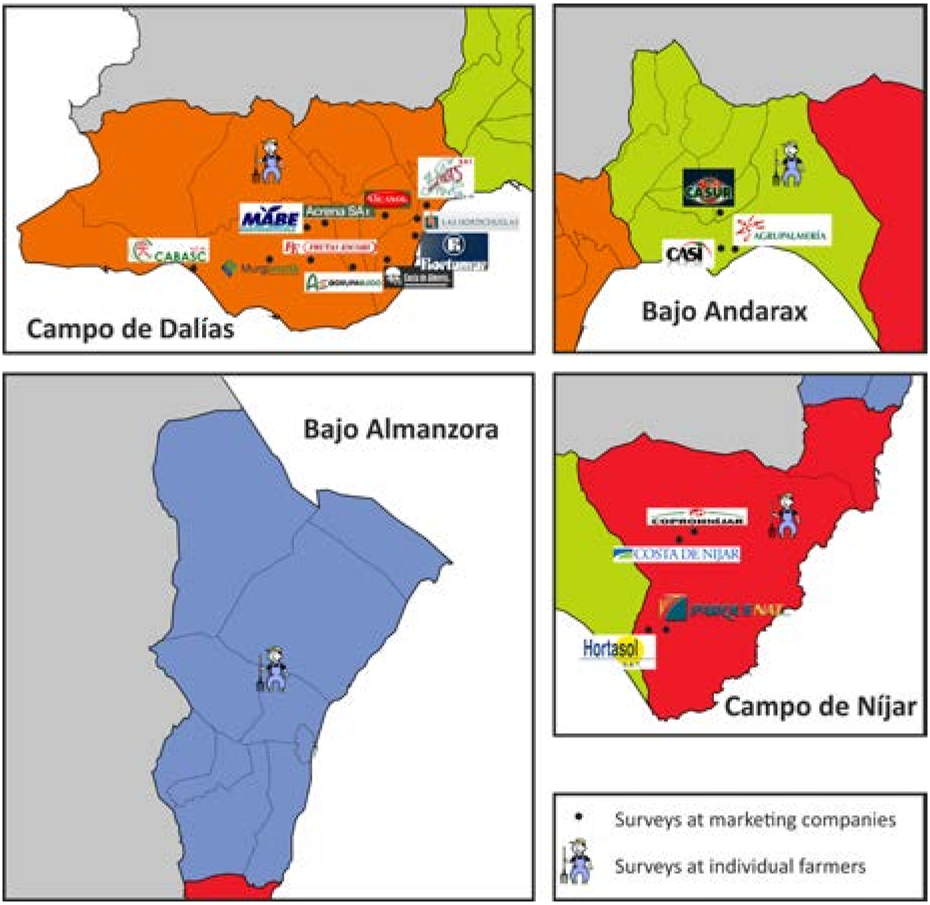
In short, this survey includes a cross-section of the intensive agriculture sector of the province of Almería, which was established by the low sampling error incurred and the methods by which farmers were selected and interviewed in the 14 municipalities.

3.3. Obtaining data from the collaborating companies

Information obtained directly from the farmers has been compared and expanded with information provided by the companies that market their products. Eighteen of the main Almería-based companies that market agricultural products participated in the study (Figure 115) and completed a data sheet that was related to the previous six agricultural seasons (from 2006/07 to 2011/12) and that included three main sections:

- Marketing data: product and variety, including volume traded in euros and kilograms.
- Data related to the holding: farm location, total surface area, greenhouse surface and type.
- Other data: acquisition of goods from vendor, crop planning according to vendor criteria and product classification systems prior to entering the warehouse.

Figure 155. Points in each region where field data were collected



4. Analysis of the greenhouse infrastructures and their economic impact

Based on the data obtained from the surveys with farmers, a comprehensive characterisation of the greenhouse production system can be obtained, both in the province of Almería as a whole and for each of the four analysed production regions. The study was conducted with 212 farmers and 685 ha of greenhouses, with the majority of surfaces located in Campo de Dalías (132), followed by Campo de Níjar (43), Bajo Andarax (28) and Bajo Almanzora (9).

In addition, data for many of the parameters corresponding to the survey conducted in 1997 (Molina-Aiz, 1997) are available as reference points, and they help reveal the impact of the productive structures in Almería over the past 16 years.

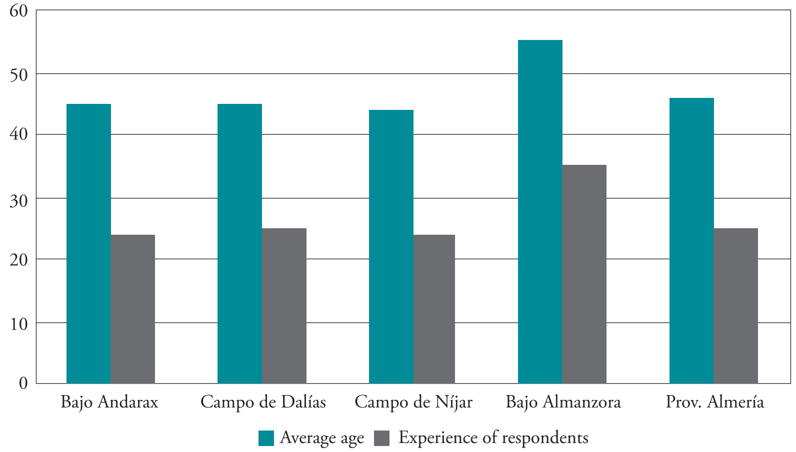
4.1. Personal data

The vast majority of the surveyed farmers are landowners (86 %) who are native to the area (92 %), have a primary education (57 %), and are on average 46 years old and have 25 years of experience.

Average age

The data for age and experience obtained in the first three regions with higher greenhouse surface (Campo de Dalías, Campo de Níjar and Bajo Andarax) were homogenous, and differences were observed with respect to farmers from Bajo Almanzora (Figure 156). The experience of the latter extends to the late 1970s (an average of 35 years, according to Figure 156) when greenhouses were barely found in the region, which indicates that in many cases, they were farmers who worked in traditional vegetable farms along the edge of the Almanzora River, which were characteristic of the entire river basin, with these farms subsequently converted into greenhouse holdings.

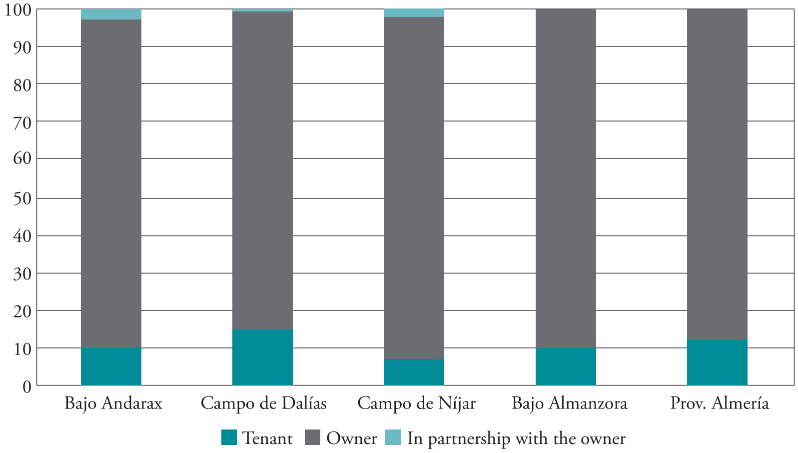
Figure 156. Average age and experience of respondents. In ages



Management of the holdings and origin of the farmers

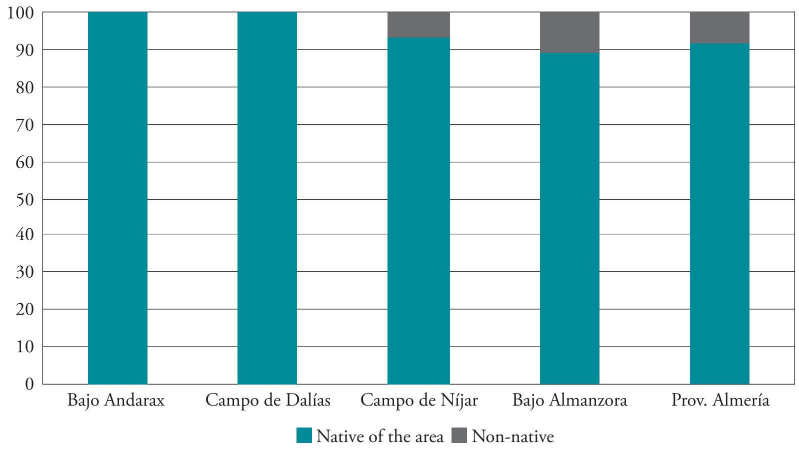
Most of the farmers own their holdings, with average ownership varying between 85 and 90 % depending on the region (Figure 157). This factor has been instrumental in the economic development of the sector and province in general because farmers who manage their own holdings are the recipients of the holdings' benefits.

Figure 157. Management regime of the holdings. In percentage



Similar to the previous case, the majority of the farmers are native to the geographical area where their holdings are located, which highlights that all the farmers from the two areas who had a horticultural tradition prior to the development of greenhouses (Bajo Andarax and Bajo Almanzora) were natives (Figure 158).

Figure 158. Geographic origin of the farmer. In percentage



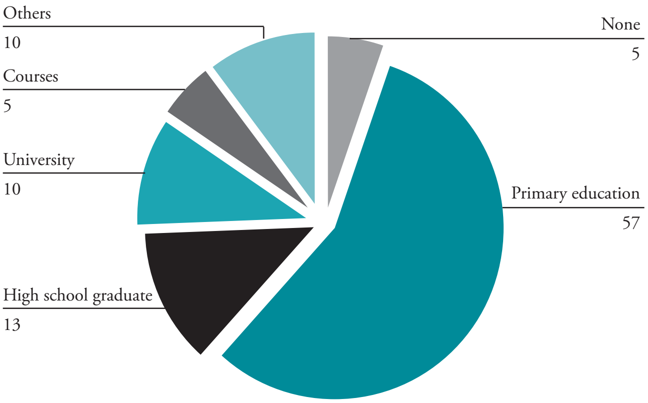
Educational level and occupation of farmers

The level of training among farmers has increased considerably in the past 16 years. In 1997, 33 % of farmers lacked education, whereas that number is currently only 5 % (Figure 159). Farmers with a high school degree currently represent 38 %, whereas in 1997, they represented 22 %. Similarly, farmers with university education have increased from 3 % to 10 %.

The education level of farmers is quite homogeneous between the different producing regions. However, the percentage of farmers today in Campo de Níjar without primary education has been reduced to 2 %, and more than half of the farmers in Bajo Almanzora have a university education (56 %), whereas in 1997, 80 % of the farmers surveyed in that region lacked basic studies.

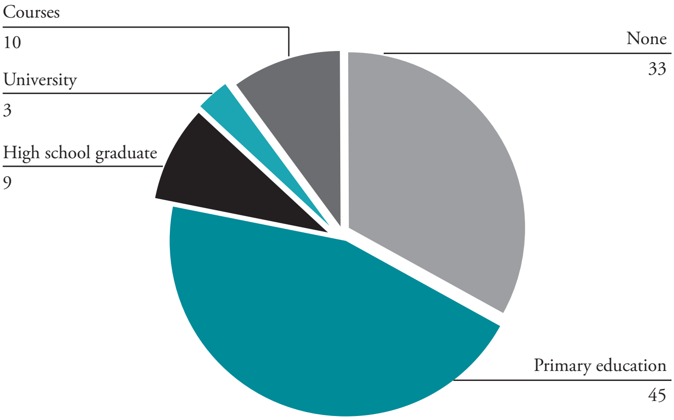
Figure 159. Evolution of the education levels of farmers between 2013 (a) and 1997 (b). In percentage

2013 (a)



Source: Survey. Own elaboration.

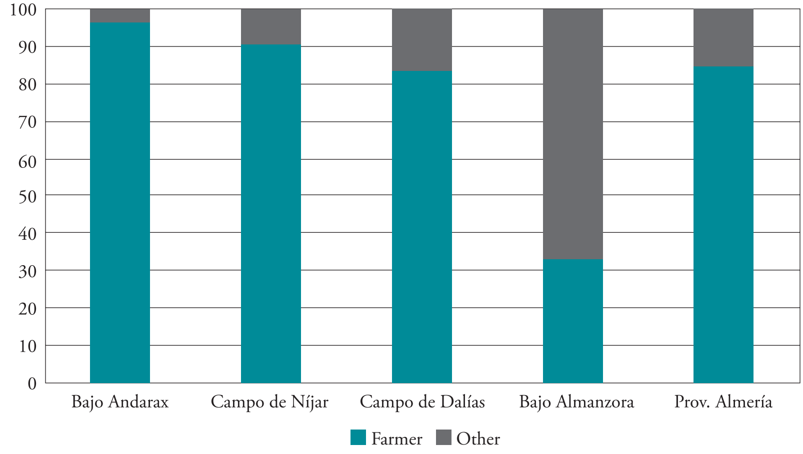
1997 (b)



Source: Molina-Aiz (1997).

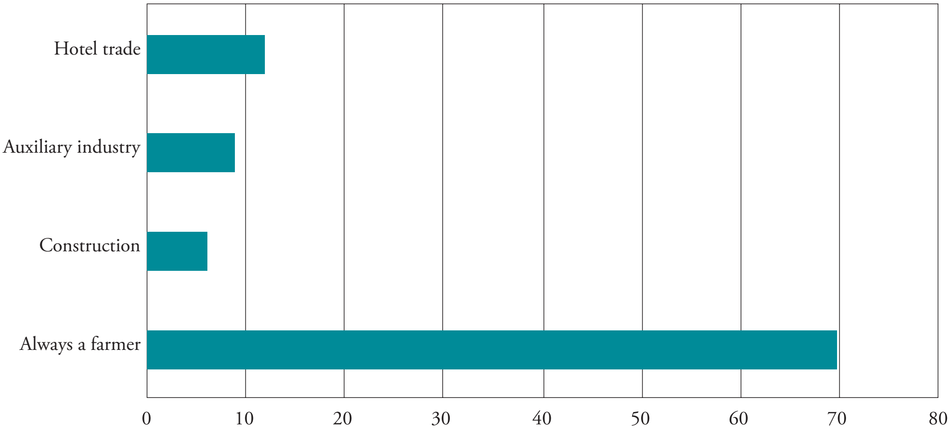
A total of 16 % of the respondents have had other occupations in addition to their work in greenhouses, and their prior work was in agriculture in 70 % of the cases (Figures 160 and 161).

Figure 160. Exclusive dedication to agriculture. In percentage



In addition, 30 % of the respondents who shifted to agricultural work were previously employed in the hospitality industry (Figure 161), and this number is related to the importance of the tourism sector in the province of Almería.

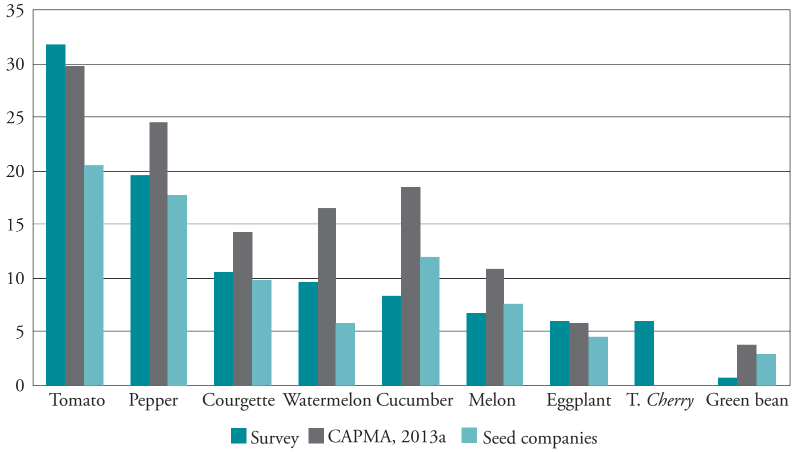
Figure 161. Employment sector prior to greenhouse labour. In percentage



4.2. Crops

The percentage of different crops that the surveyed farmers sowed or transplanted in their greenhouses (Figure 162) is similar to the surface distribution of the entire province as calculated by the Regional Government of Andalusia and estimated from data provided by several seed companies. The main greenhouse crop in Almería is tomato, which represents 37.7 % of the total (including the cherry tomato), followed by pepper, which represents 19.5 % of the growing surface. Five crops had similar percentages (between 6 and 10 %): cucumber, watermelon, courgette, melon and eggplant. Green bean crops were only found at 0.7 %, thus representing the least widespread crop.

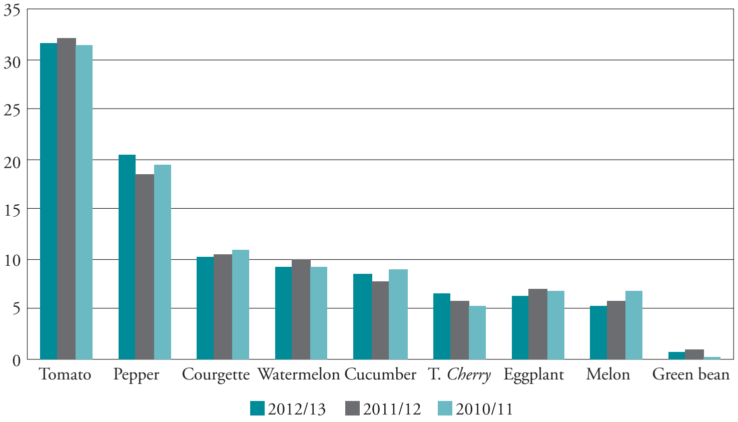
Figure 162. Crops grown by farmers surveyed in the last three seasons and estimations of the total surface area in the province conducted by the Regional Government of Andalusia and seed companies. In percentage



Source: Regional Government of Andalusia (CAPMA, 2013a).

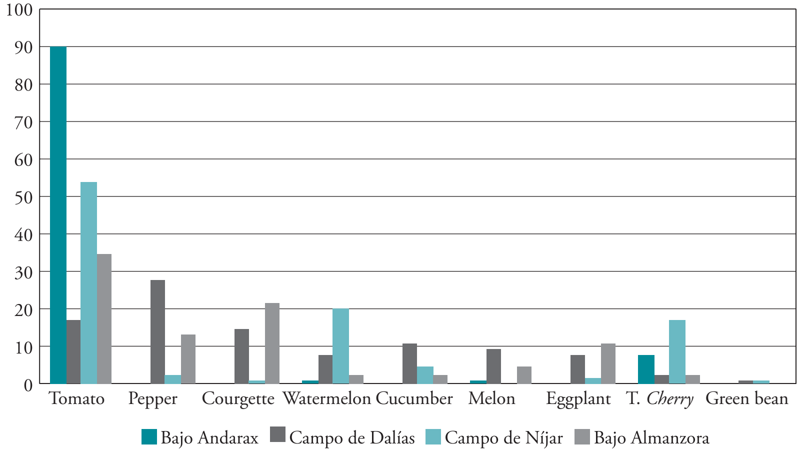
The analysis of the last three agricultural seasons (Figure 163) shows a high degree of homogeneity, as in 80.9 % of the cases studied, farmers repeated crops two years in a row, which indicates that farmers specialise in certain crops and pass their knowledge on from one season to the next. The results also reflect the regulation efforts by the marketing companies that promote advanced knowledge of the crops to be sown (as indicated by the consistency between data from the seed companies and that of surveys), thus facilitating the regulation of prices.

Figure 163. Crops grown by farmers surveyed in the last three seasons. In percentage



In addition, there were large differences in crop distribution in each of the four production areas (Figure 164).

Figure 164. Crops grown by farmers surveyed in the last three seasons in the different producing regions of Almería. In percentage



The analysed data show that there is strong specialisation in tomato in the Bajo Andarax and Campo de Níjar regions, where it accounts for 97.8 % and 71.1 % of the crops, respectively (Figure 164). In Campo de Níjar, watermelon accounts for 19.7 % and corresponds to the spring-summer crops that follow the first short-cycle tomato crop in autumn-winter. Finally, virtually all the producers of Bajo Andarax (97.7 % of the respondents) grow long-cycle tomato crops.

The high degree of specialisation of the Bajo Andarax and Campo de Dalías regions is related to their edaphoclimatic characteristics, which increases their suitability for growing tomato. The soils of this geographical area are of a sodium-saline type and are characterised by high soluble salt contents. As a result, they also have high electrical conductivity values (CE > 6 dS m^{-1}), a high percentage of exchangeable sodium (PSIc > 10), and pH values lower than 8.5. Similarly, the effect of the Mediterranean Sea on the climate of the area provides thermal conditions that are ideal for the growing of tomato.

This specialisation was recognised by the Order of the Ministry of Agriculture and Fisheries of the Andalusian Regional Government on 30 January 2008 (BOJA No. 28 of 8 February 2008) with the granting of the Protected Geographical Indication «Tomate La Cañada». The subsequent Order of 17 January 2012 (BOJA No. 16 of 25 January 2012) modified the statement of conditions, indicating, among other things, a prohibition of farming techniques involving artificial modifications of the climate, soil, or water. This prohibition includes artificial climate control systems (heating, fog systems, or carbon dioxide enrichment) because the specific climate (incident radiation, temperature, humidity and prevailing winds), water and soils of the geographical area affect the tomatoes and impart specific and differential characteristics. With the Implementing Regulation Nº 487/2012 from the European Commission on 7 June 2012, the name «Tomate La Cañada» was registered in the Register of Protected Designation of Origin and Protected Geographical Indications of the European Union (Official Journal of the European Union L 150/67 of 9 June 2012).

In the Bajo Almanzora region, the most important crop is also tomato, which accounts for 37 % (including the cherry tomato), followed by cucumber (21.7 %), pepper (13 %) and eggplant (10.9 %).

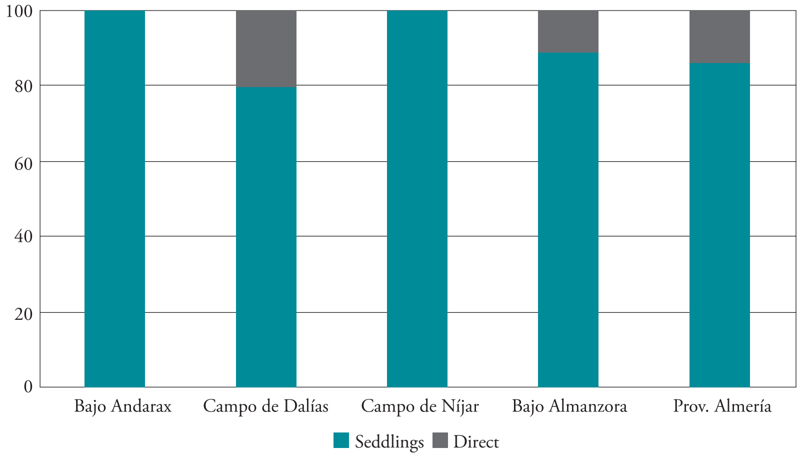
In Campo de Dalías, the most important crop is pepper, which accounts for 27.7 % of the production, followed by tomato, which accounts for a distant 19.8 %. Significant differences are not observed in the production distribution of cucumber, courgette, melon, eggplant and watermelon, which have values ranging from 14.3 % for cucumber to 7.8 % for eggplant and watermelon.

Sowing and seedling preparation

The majority of farmers (86.1 %) transplant seedlings that are grown in nurseries (Figure 165), especially in the Campo de Níjar and Bajo Andarax regions because of their tomato crop specialisation, which is usually not sown in the greenhouse but transplanted. In Campo de Dalías, only 20.3 % of the respondents reported that they practiced direct seeding, which is related to the great importance of crops in this region that can be sown directly, such as cucumbers, courgette, and melon.

The preparation of seedlings for transplantation is performed in nurseries in almost all cases (95.3 %). Only 2 % of the farmers of Campo de Dalías have their own hotbed for seedlings that are later transplanted to greenhouses.

Figure 165. Seedling transplant procedures in the different regions and in the province as a whole. In percentage



Weed control and foliar analysis

The elimination of weeds inside the greenhouses is performed mostly by hand, with 34 % of the cases exclusively by hand, 16 % with the help of herbicides and 39.6 % by hand together with tools (Figure 166). Only 2.7 % of the farmers control weeds exclusively with herbicides, and 3.6 % do not control weeds at all, which corresponds to the cases that grow crops in substrate.

Manual weeding mostly occurs in the Bajo Andarax and Bajo Almanzora regions because they retain a strong horticultural tradition, and this technique is connected with cultural factors that predate the introduction of greenhouses.

The majority of farmers (91 %) conduct foliar analyses to control the amount of required fertilisation of the soil (Figure 167). Most of the analyses are conducted through cooperatives, which emphasises the importance of consulting work conducted by agricultural technicians for crop monitoring and deficiency corrections in the production process. The fundamental role of technicians who provide advice to farmers in greenhouses in Almería will be reinforced in the future by the Royal Decree 1311/2012 of 14 September, which has yet to come into effect. This regulation establishes a provision of technical advice for farmers with regard to integrated pest management (BOE No. 223 of 15 September 2012), which must be performed through a contract.

Figure 166. Methods of weed control. In percentage

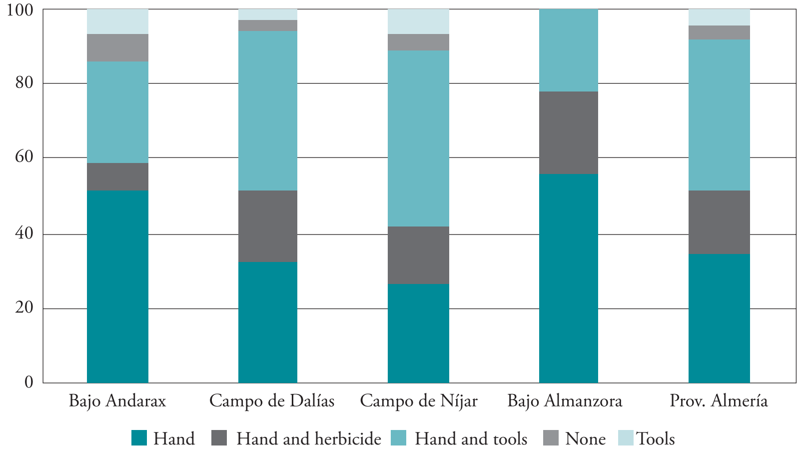
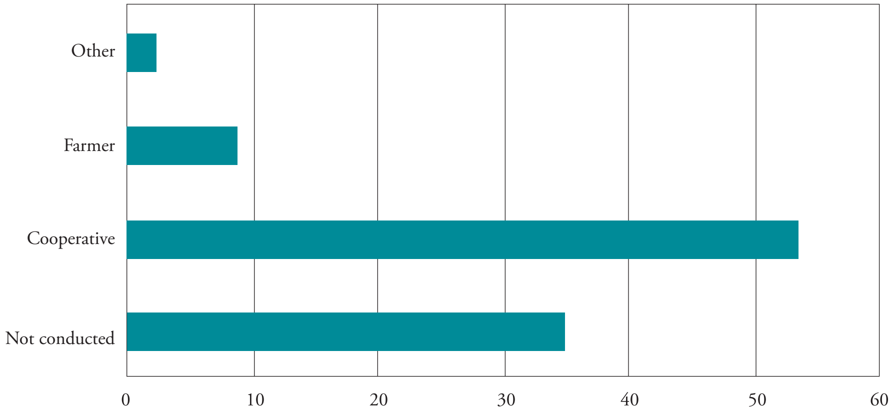


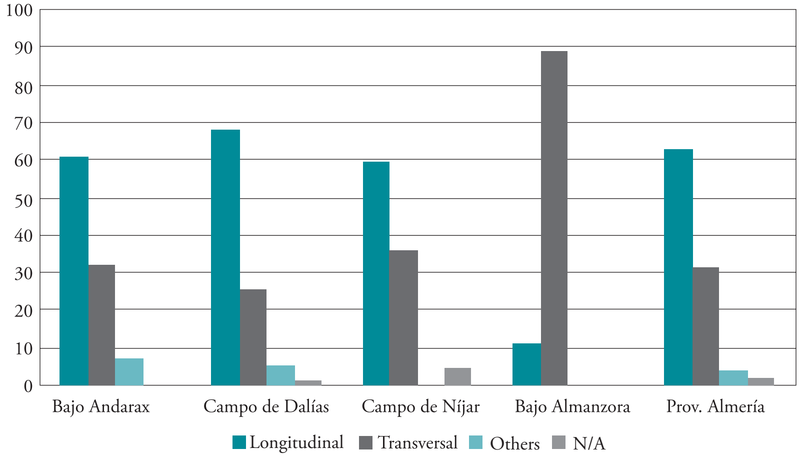
Figure 167. Foliar analyses conducted. In percentage



Crop layout in the greenhouse

In 63 % of the sampled greenhouses, plant lines are arranged in the same direction as the ridge of the greenhouse (Figure 168), which, in 76.9 % of the cases, is a north-south (N-S) orientation, although in the Campo de Dalías region, 55.6 % of the greenhouses follow an east-west (E-W) orientation (section 4.7, Figure 214).

Figure 168. Orientation of crop lines. In percentage



Is also worth noting that in Bajo Almanzora, 89 % of the farmers arrange plant lines perpendicular to the ridge, which is in contrast to the other regions. The arrangement of plant lines is closely related to the orientation of the corridors inside the greenhouse, and 65.9 % of greenhouse corridors are arranged transversely to the ridge (70 % longitudinal in Bajo Almanzora). Crop lines are almost always perpendicular to the corridors so that major irrigation lines can be placed parallel to the corridor and the aisles between crop lines are shorter.

The orientation of plant lines affects crops in two different ways: it determines the interception of solar radiation throughout the day and year and influences air flow through the plant canopy. The effect of line orientation on the interception of photosynthetically active radiation (PAR) varies depending on the time of day, season, latitude and geometry of the crop (Jackson, 1980). Thus, for latitudes of 35º N that are adjacent to areas occupied by greenhouses in Almería (between 36.5º and 37º N), the E-W crop line orientation allows for greater daily irradiation than the N-S orientation during the winter months and the beginning of spring when crops require the most light (Li *et al.*, 2000), whereas the opposite trend occurs in the summer-autumn periods (Jackson and Palmer, 1972; Ferguson, 1960).

Similarly, crop lines are oriented perpendicular to the outside wind direction, which is normally parallel to the ridge and thus to roof windows. This results in a reduction of air speed in the plant canopy. Accordingly, decreases in air speed between 28 % and 63.89 % have been reported as a result of the greater aerodynamic resistance in this arrangement compared with an arrangement that is perpendicular to the ridge and parallel to the wind direction (Sase, 1989; Boulard *et al.*, 1997, Kacira *et al.*, 2004b). When plants are arranged parallel to the wind, the air flow enters the canopy through the aisles between two crop lines (López, 2011), thus reducing the opposing resistance that would occur if the plants were placed perpendicular to the air movement (Fatnassi *et al.*, 2009). In Almería-type greenhouses, this effect is reduced by the availability of side windows in all bands of the greenhouse, which allows the passage of air between rows of plants.

As shown in Table 17, variability in plantation density is greater between crops than between geographical areas. In Campo de Níjar, which is one of the areas most specialised in growing tomato, there is a density of 1.72 plants/m^2, which is considerably higher than the average of the province and other regions (Table 17). The plantation density of watermelon crops

(0.29 plants/m^2) is much lower than that of other crops, whereas peppers can be grown to densities up to 2 plants/m^2, which is related to growth characteristics of the plants.

Table 17. Plantation densities for each of the crops in the different producing regions and in the province as a whole. In plants/m^2

Region	Tomato	Cucumber	Pepper	Courgette	Green Bean	Watermelon	Melon	Eggplant
Bajo Andarax	1,36							
Campo de Dalías	1,30	1,05	1,91	0,94	0,69	0,31	0,85	0,66
Campo de Níjar	1,72		2,00	0,81	1,00	0,25		
Bajo Almanzora	1,48	1,26	1,50	1,00		0,55	2,00	2,00
Provincie of Almería	1,48	1,07	1,90	0,93	0,75	0,29	0,89	0,77

In general, higher densities are observed in Bajo Almanzora, which could be related to the differences in the orientation of the crop lines and differences in the climate of this region compared with that of the other three regions. In the case of the melon, different densities occur because the Galia melon is grown in this region, and it presents tall growth and is trellised, which permits a greater density than creeping varieties.

Planting density is a factor that directly affects the production of greenhouse crops. Thus, in the case of tomato, higher yields can be obtained with a higher planting density (3 plants/m^2) than for lower densities (Papadopoulos and Pararajasingham, 1997). Higher production by denser crops may be related to increased biomass production associated with increases in PAR interception. These increases may be related to two factors: increases in the amount of biomass promote a greater number of fruit and a greater leaf area index (LAI), which intercepts a greater proportion of PAR (Papadopoulos and Pararajasingham, 1997).

Yield of greenhouse crops

The average crop yield of the regions is variable (Tables 18 and 19) and depends on a number of factors analysed in this study: crop type, climatic zone, irrigation water quality, structure type, ventilation surface, climate control system, crop management, etc. The following two tables show the mean yields of the past three agricultural seasons (from 2010/11 to 2012/13) ordered by region in Table 18 and by greenhouse type in Table 19.

Eggplant has shown an average performance in Almería-type greenhouses of approximately 7 kg m^{-2} for short cycles and 12.65 kg m^{-2} for long cycles. Production of courgette did not show an increase with the use of more expensive structures, such as the multi-span compared with the Almería-type greenhouse, with an average yield of 4.24 kg m^{-2} for the autumn-winter cycle and 5.01 kg m^{-2} for the spring-summer cycle. The average green bean yield has been 3 kg m^{-2}, average melon yield has been 4.6 kg m^{-2}, and average watermelon yield has been 6.14 kg m^{-2}. Production differences caused by the structure have been observed for cucumber, with an autumn cycle average yield of 10.75 kg m^{-2} for the Almería-type greenhouse and 12.67 kg m^{-2} for the multi-span. The mean yield for the autumn-winter cycle has been 10.64 kg m^{-2}, which increases to 12.43 kg m^{-2} in the spring-summer cycle.

For a better understanding of the results obtained for pepper, and because of its importance in Almería, especially in the Campo de Dalías region, they have been separated into four different types: California and Lamuyo, Ramiro types (includes Urano and Palermo), sweet Italian, and others (hot and snack peppers).

The yield of California and Lamuyo peppers is approximately 7.4 kg m^{-2} in Almería-type greenhouses, which have shown better performance than the multi-span greenhouses. Because of the greater specialisation in Campo de Dalías, farmers in this region have produced 1.5 kg m^{-2} more peppers than in the other three regions. The average yield for the sweet Italian pepper, Ramiro, and hot and snack peppers has been 11.6 kg m^{-2}, 13.96 kg m^{-2}, and approximately 10 kg m^{-2}, respectively.

The main crop in Almería is tomato, which has been recorded by 212 farmers in all regions, all cycles, and all types of greenhouse structures. Because of its special characteristics, we have excluded the cherry tomato from other types of tomatoes.

Yields for tomato are homogeneous by region, especially in the spring-summer cycle. These crops have performed similarly for all types of greenhouse structures except for the long cycle, where the greatest yield for tomato was obtained in multi-span greenhouses.

An average tomato yield of 9 kg m^{-2} was recorded for the autumn-winter cycle, 11.64 kg m^{-2} was recorded for the spring-summer cycle, and 16.79 kg m^{-2}

Table 18. Average yields (kg m^{-2}) for each of the crops in the different production regions depending on the crop cycle

			Eggplant	Courgette	Green Bean	Melon	Cucumber	California + Lamuyo Pepper	Sweet Italian Pepper	Ramiro Pepper	Other Peppers (hot and snack)	Watermelon	Tomato	*Cherry* Tomato
Short cycle	**Autumn**	Bajo Andarax											9,06	
		Campo de Dalías	7,00	4,22			10,79	7,51			10,00		10,56	10,00
		Campo de Níjar		4,00				6,00					8,72	5,80
		Bajo Almanzora		5,00			9,00						6,00	
		Provincial total	**7,00**	**4,24**			**10,64**	**7,49**			**10,00**		**9,00**	**6,50**
	Spring	Bajo Andarax				4,00						3,00	11,60	
		Campo de Dalías	8,00	5,01	3,00	4,61	12,43	7,30				6,21	11,74	8,00
		Campo de Níjar		5,00								6,22	11,53	
		Bajo Almanzora	6,83									6,00	11,33	
		Provincial total	**7,42**	**5,01**	**3,00**	**4,60**	**12,43**	**7,30**				**6,14**	**11,64**	**8,00**
Long cycle		Bajo Andarax											16,91	12,42
		Campo de Dalías	12,73						11,60	14,45	11,75		15,59	11,00
		Campo de Níjar	10,00							11,50			17,69	12,09
		Bajo Almanzora									7,25		17,50	12,00
		Provincial total	**12,65**						**11,60**	**13,96**	**9,50**		**16,79**	**11,88**

Table 19. Average yield (kg m^{-2}) for each of the crops according to the type of greenhouse used

			Eggplant	Courgette	Grean bean	Melon	Cucumber	California + lamuyo pepper	Sweet italian pepper	Ramiro type pepper	Other peppers (hot and snack)	Water-melon	Tomato	*Cherry* tomato
Autumn cycle	Almería type	'Parral plano'		3,59			9,25	7,54					8,38	
		'Raspa y amagado'	7,00	4,48			9,74	7,52					9,20	6,88
		Asymmetric		4,00			13,25	7,18			10,00		12,00	
	Multi-span	Cylindrical					12,67						9,00	
		Gothic		4,00				5,00						
	All types		**7,00**	**4,24**			**10,64**	**7,49**			**10,00**		**9,00**	**6,50**
Spring cycle	Almería type	'Parral plano'		4,66		4,40	11,50					4,50	12,25	
		'Raspa y amagado'	7,38	4,77	3,00	4,65	13,38	7,30				5,99	11,58	8,00
		Asymmetric		6,00		4,76	9,50					6,75	10,75	
	Multi-span	Cylindrical				4,50								
		Gothic		6,00								8,00	12,50	
	All types		**7,42**	**5,01**	**3,00**	**4,60**	**12,43**	**7,30**				**6,14**	**11,64**	**8,00**
Long cycle	Almería type	'Parral plano'	11,38						11,60	11,00			15,95	
		'Raspa y amagado'	13,50						11,60	15,29	9,50		16,24	12,06
		Asymmetric	11,00							9,50			15,19	11,75
	Multi-span	Cylindrical											18,54	9,00
		Gothic											15,00	13,00
	All types		**12,65**						**11,60**	**13,96**	**9,50**		**16,79**	**11,88**

was recorded for the long cycle; for the cherry tomato, the average results for the different cycles were 6.5 kg m^{-2}, 8 kg m^{-2} and 11.88 kg m^{-2}, respectively.

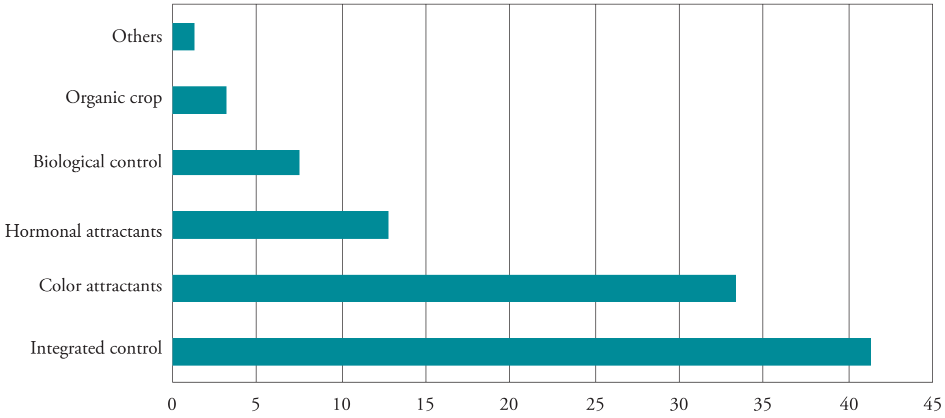
The average yields of tomato in greenhouses in Almería are much lower than those reported in countries such as Holland, which reported 56.5 kg m^{-2} from heated Venlo glass greenhouses (van Zundert, 2012), Canada, which reported 56.4 kg m^{-2} from heated plastic greenhouses (Hendricks, 2012), or France, which reported 44.0 kg m^{-2} from heated plastic covered multi-span greenhouses (Boulard *et al.*, 2011). However, the greenhouses in Almería are more energy efficient and obtain higher production yields in kilograms produced per unit of energy consumed (Table 12). In addition, the average tomato production in Almería (16.8 kg m^{-2}) is competitive against other greenhouses without heating, such as in France, which reported an average of 14.6 kg m^{-2} (Boulard *et al.*, 2011), and Italy, which reported 9.6 kg m^{-2} (Cellura *et al.*, 2012).

Alternative systems for pest control

Most farmers use alternative or complementary techniques in addition to traditional pest control through the use of phytosanitary treatments. In addition, 42 % of the farmers (Figure 169) have opted for integrated control, which involves the use of pest control techniques that simultaneously satisfy economic, ecological and toxicological demands, thus prioritising the use of natural elements and respecting tolerance levels (Brader, 1975).

A total of 7 % of the farmers conducted biological control exclusively, which is an even more restrictive technique that includes methods of eliminating insects through the rationed use of natural enemies from the animal and vegetable kingdoms (Balachowsky, 1951), such as entomophagous insects (parasites and predators of insects and mites) and entomopathogenic microorganisms (fungi, bacteria or viruses) (Benassy, 1977).

Figure 169. Alternative or supplementary procedures for phytosanitary products. In percentage

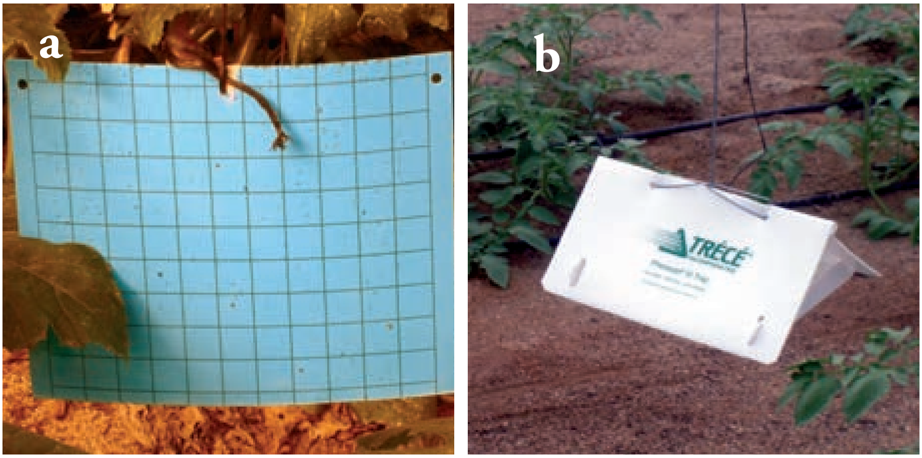


A small percentage of farmers (3 %) incorporate organic farming's restrictions on the use of chemicals in the greenhouse, which was initially regulated by the Regulation (CEE) No. 2092/91 of the European Council on 24 June 1991 (OJ L 198 of 22 July 1991) on organic agricultural production and provide indications referring to agricultural products and foodstuffs; subsequently, these regulations were established at both the national and regional level. At a regional level, these practices are regulated by Decree 166/2003 of 17 June 2003 (BOJA No. 117 of 20 June 2003) on ecological agri-food production in Andalusia, which establishes the methods of control and monitoring in Andalusia.

Thirty-four percent of farmers use colour traps (Figure 170a) for pest control and to monitor infection levels in the greenhouses, whereas 13 % use hormonal attractants (Figure 170b) as a complement to the use of phytosanitary products. The blue and yellow adhesive traps distributed throughout the greenhouse, as well as the use of pheromones for the capture of pests whenever possible, are mandatory measures included in the Specific Regulations of the Integrated Production of Protected Horticultural Crops.

The use of hormonal attractants in traps has proven to be an effective tool against the recent plague of Tuta absoluta (Filho *et al.*, 2000; Abbes and Chermiti, 2011), which causes significant economic damage for the agricultural sector (Desneux *et al.*, 2010), as well as against other greenhouse pests (Witzgall, 2001; Witzgall *et al.*, 2010).

Figure 170. Blue traps used for pest control (a) and pheromone traps used for Tuta absoluta control in the greenhouses of Almería (b)



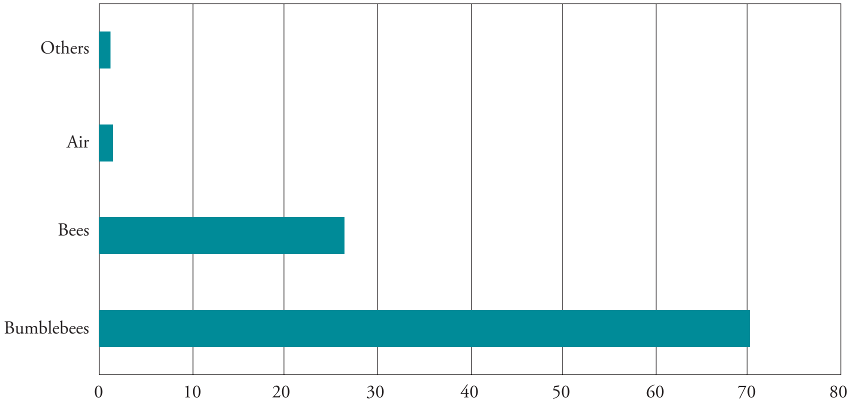
Blue and yellow colour traps are an effective method of controlling and reducing pests, and they provide early detection of the presence of insects and their number in the greenhouse (Byrne *et al.*, 1986; Park *et al.*, 2001; Qiao *et al.*, 2008). These traps have become an essential element in pest control systems (Byrne *et al.*, 1986; Gillespie and Quiring, 1992; Heinz *et al.*, 1992; Steiner *et al.*, 1999; Park *et al.*, 2001). In addition, they are used to estimate the level of infection and to reduce insect populations when combined with other control techniques (Moreau and Isman, 2012).

It is important to note that in the greenhouses of Bajo Almanzora, organic farming accounts for 40 % of the production in greenhouses, whereas integrated control without the use of hormonal attractants accounts for 7 %. These results are similar in other regions and similar to the average of the province, although in the case of Bajo Andarax, integrated control accounts for 58 %, which is possibly a result of its specialisation in growing tomato.

Methods of pollination and grafting

In 96.9 % of the surveyed cases, farmers perform flower pollination with auxiliary insects, primarily bumblebees, which account for 70.3 % (Figure 171). Only 1.5 % of the farmers use air blowers to accomplish this task.

Figure 171. Pollination methods. In percentage

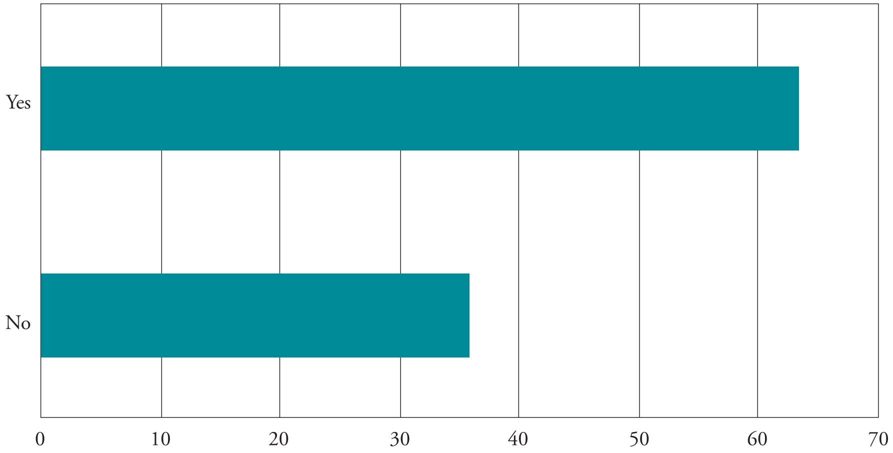


The use of blowers for vacuum dusting during the middle of the day is a technique recommended by the Specific Regulations of the Integrated Production of Protected Horticultural Crops when the conditions for pollination in summer are highly unfavourable. This regulation also recommends the placement of bee hives (Apis mellifera) or bumblebees (Bombus terrestris) to improve pollination and to minimise the number of low-quality fruits.

It is remarkable that 100 % of the surveyed farmers in Bajo Andarax and Bajo Almanzora use bumblebees as the only method of pollination. In the other two regions, the results are similar to the average in the province

Regarding the use of grafts, 63.8 % of the surveyed farmers use grafted crops (Figure 172) for tomatoes, watermelon and eggplant, and only a limited number use grafts for peppers. The remaining crops (cucumber, courgette, melon and green beans) are planted directly in the greenhouse.

Figure 172. Use of grafts and distribution by crop. In percentage



4.3. Machinery

A fundamental aspect that influences the production in greenhouses in Almería is the level of mechanisation of horticultural work.

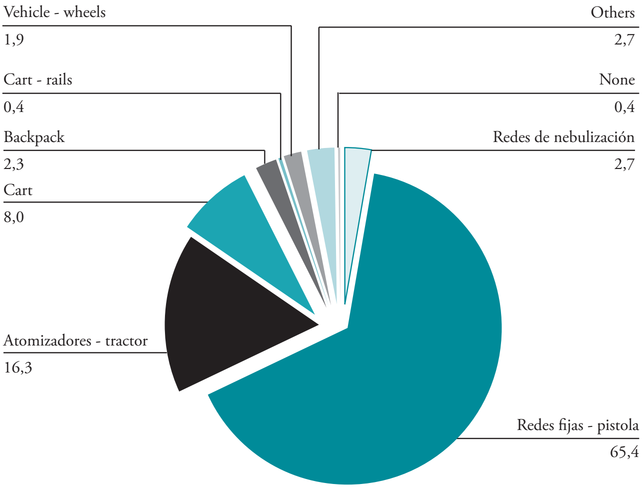
Machinery for the application of phytosanitary treatments

The machinery used to apply phytosanitary treatments has advanced significantly over the past 16 years (Figure 173), and a number of new equipment types and technologies have emerged, thus enabling farmers to diversify the methods used for treatment application. Today, networks of fog systems account for 2.7 % of the total, whereas in 1997, 0 % of the 526 assessed greenhouses had incorporated this technique. The number of greenhouses that use the traditional system of fixed networks of hydraulic spraying has reduced significantly from 94.1 % in 1997 to 65.4 % today. In addition, the two systems used as alternatives to these stationary systems in 1997 (hydro-pneumatic atomisers attached to tractors and semi-autonomous mobile cars) are the two major alternatives today, and their use has increased from 0.9 % and 1.0 % in 1997 (Figure 173b) to 16.3 % and 8.0 % in 2013 (Figure 173a), respectively.

Also noteworthy is the current use of wheeled vehicles, which are primarily employed in the Bajo Andarax region, where they account for 11 %; this result was likely influenced by the location of the leading manufacturer of this type of equipment, which is in the same region.

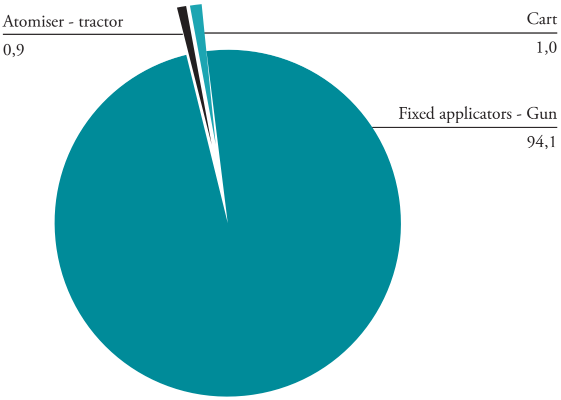
Figure 173. Evolution of machinery used for phytosanitary treatments between 2013 (a) and 1997 (b). In percentage

2013 (a)



Source: survey. Own elaboration.

1997 (b)



Source: Molina-Aiz (1997).

Regarding the use of different techniques by region, in Bajo Almanzora, 30 % of the farmers use semi-suspended tractor-mounted hydro-pneumatic atomisers (cannons) and the remainder use traditional hydraulic spraying systems. It is also interesting to note the high use of networks of hydro-pneumatic fog systems in the Campo de Níjar region, where they are installed in 8 % of the greenhouses. This area also presents significant use of cannons that are semi-suspended on the tractor (22 %), and the use of traditional hydraulic spraying networks has been reduced in this region to 45 %.

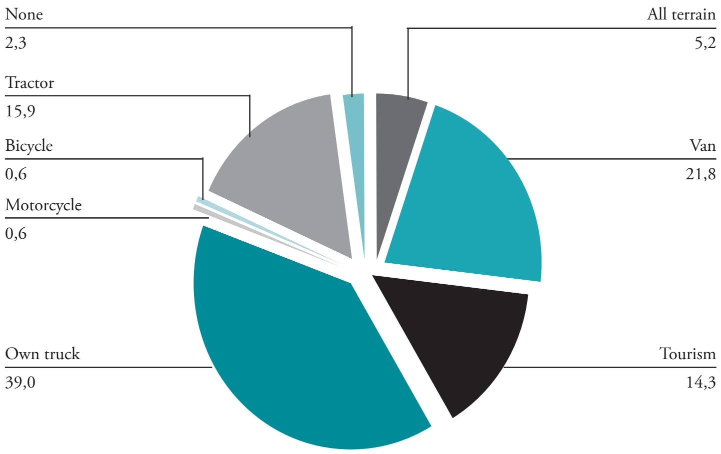
In Campo de Dalías, there is an increased use of fixed spray networks (74 %) and reduced use of trolleys (3 %).

Vehicles used in the operation

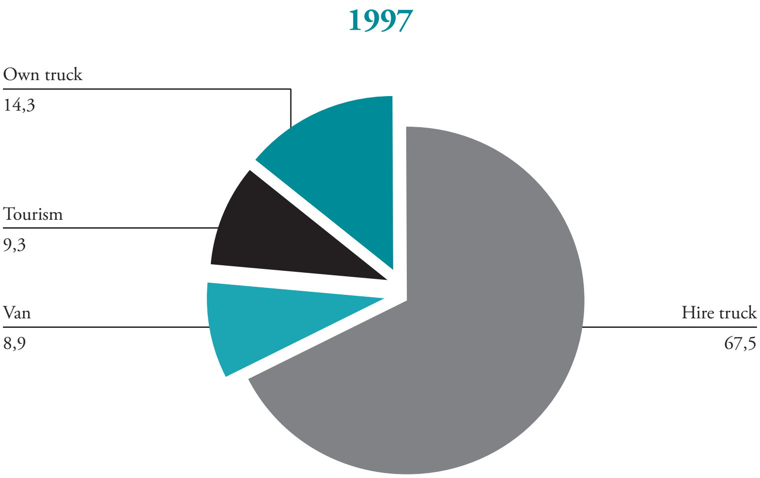
The vehicles used by farmers are now diversified (Figure 174), with the use of vans increasing from 8.9 % in 1997 to 21.8 % in 2013; in addition, passenger cars with trailers and all-terrain vehicles now account for 19.5 %, compared with 9.3 % in 1997. The use of trucks has also reduced to 39 %.

Figure 174. Evolution between 2013 (a) and 1997 (b) of the use of vehicles by farmers in agricultural operations. In percentage

2013



Source: survey. Own elaboration.



Source: Molina-Aiz (1997).

4.4. Soil

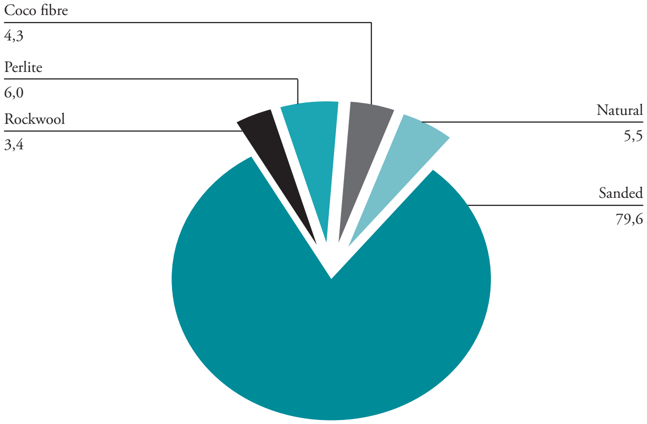
One of the most influential factors in a greenhouse is the soil type. The use of substrates provides greater control of fertigation and tends to be associated with increased technological investments, both in structure and climate control systems. However, the use of sanded soil increases the heat absorption in the zone occupied by the root system and provides greater moisture stability in this zone (Mendizabal and Verdejo, 1959; Fernández and Pizarro, 1981), which favours root growth of the crops (Castilla *et al.*, 1986).

Soil type

The type of soil used has changed little over the past 16 years throughout the province (Figure 175), and sand plots are still the main type of soil, with a minor increase from 78.4 % in 1997 to 79.6 % today. The use of rockwool, perlite and peat has been considerably reduced in favour of natural soil (5.5 % currently compared to 0.4 % in 1997), and coconut fibre, which was not available 16 years ago, now represents 4.3 %.

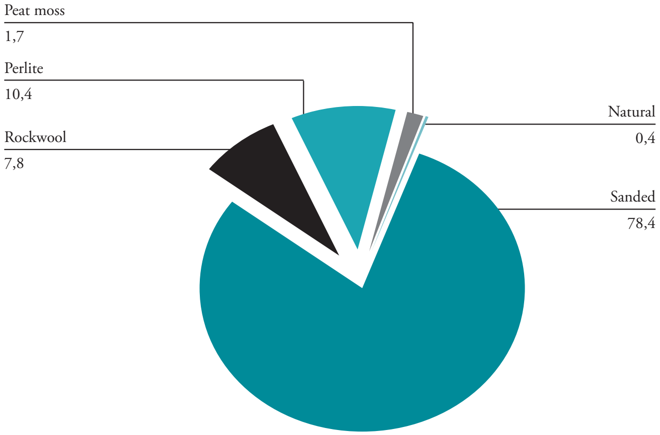
Figure 175. Evolution between 2013 (a) and 1997 (b) of soil type in Almería greenhouses. In percentage

2013



Source: survey. Own elaboration.

1997



Source: Molina-Aiz (1997).

An analysis of the soil use in the different regions (Table 20) shows a fundamental increase in the use of natural soil in Bajo Almanzora of up to 66.7 %, whereas in 1997, crops were only grown in sand plots. This result is possibly because of the implementation of new production areas on native soil, whereas the old holdings were constructed with sanded soil.

Table 20. Evolution of soil type of greenhouses in the different regions between 2013 and 1997. In percentage

Region	Natural		Sand plots		Rockwool		Perlite		Coco F.	Peat
Surveyed	**2013**	**1997**	**2013**	**1997**	**2013**	**1997**	**2013**	**1997**	**2013**	**1997**
C. de Dalías	3,9	0,0	78,6	72,4	2,6	11,2	9,1	13,9	3,9	2,5
Campo de Níjar	2,3	1,0	86,4	97,0	2,3	1,0	0,0	1,0	9,1	0,0
Bajo Andarax	0,0	2,5	89,3	77,5	10,7	0,0	0,0	0,0	0,0	0,0
Bajo Almanzora	66,7	0,0	33,3	100,0	0,0	0,0	0,0	0,0	0,0	0,0

Table 20 shows that Bajo Andarax currently has 10.7 % of its crops in rockwool, a medium previously unused in that locality. This contrasts with the low usage in the Campo de Dalías and Campo de Níjar regions, where its use is restricted to 2.3-2.6 %. The table also indicates that perlite is used only in Campo de Dalías at 9.1 %, whereas in 1997, its use was at 13.9 %. In addition, the use of sanded soil in this region has increased from 72.4 % in 1997 to 78.6 % currently, and peat, which is currently not used, appears to have been replaced by coconut fibre.

In Campo de Níjar, crops in sand plots have reduced from 97 % to 86.4 % today, and this reduction has been caused by the availability of coconut fibre, which represents 9.1 % of the greenhouses today, and the slight increase in the use of natural soil and rockwool.

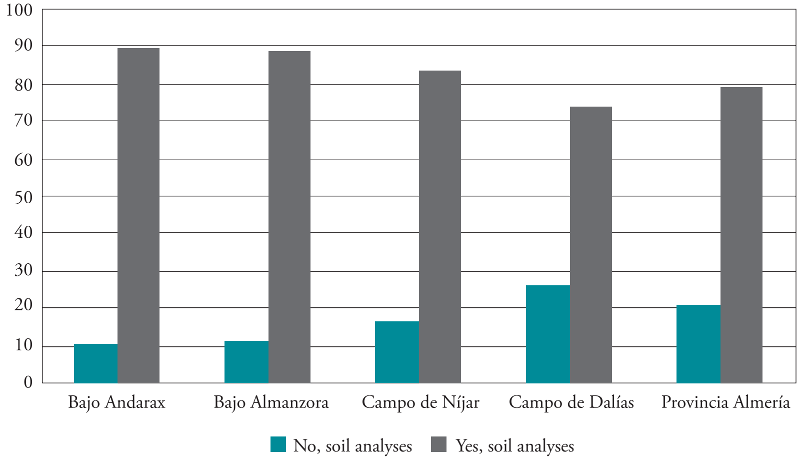
Recirculation of the nutrient solution is performed in 60 % of the soilless crops in Campo de Níjar and 3.8 % in Campo de Dalías, which accounts for only 11.8 % of all greenhouses with substrate growing in the entire province.

Soil analysis and disinfection

The majority of farmers (79 %) perform soil analyses to control fertility, and values of 89 % have been obtained in both Bajo Andarax and Bajo

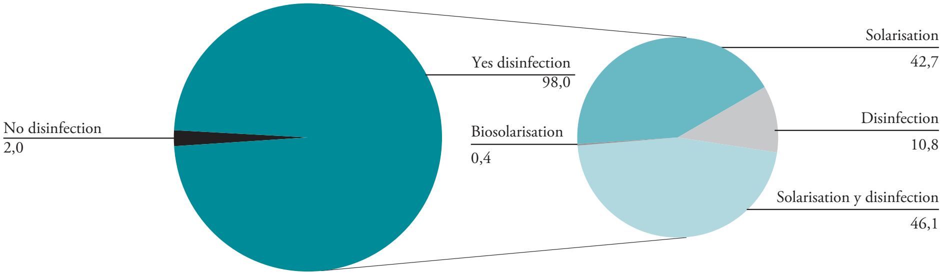
Almanzora (Figure 176). Soil analysis is less common in Campo de Dalías, where this control measure is only conducted by 74 % of farmers.

Figure 176. Percentage of farmers that conduct soil analyses. In percentage



A majority (98 %) of farmers disinfect their greenhouse soils (Figure 177), which is performed primarily through the technique of solarisation (42.7 %) or by the combination of solarisation with chemical disinfection (46.1 %). Only 10.8 % of surveyed farmers use chemical disinfectants. Also noteworthy is the use of biosolarisation in 0.4 % of greenhouses, corresponding to the Campo de Dalías region.

Figure 177. Percentage of farmers that conduct soil disinfection



The use of solarisation as a single system of soil disinfection is at 59 % in Campo de Níjar, with the combined use of solarisation with chemical disinfectants reduced to 28 %. In Bajo Almanzora, 100 % of the surveyed farmers disinfect the soil using solarisation, and 27 % combine this technique with the application of chemical disinfectants.

The first soil disinfection treatments consisted of chemical biocides or various forms of heat application (Pullman *et al.*, 1981), which were performed to reduce the transportation of inoculum through the soil by crop pests, such as fungi, bacteria, pathogenic nematodes, weeds, and certain insects. These treatments protect and stimulate root growth and crop production as a result of changes in the micro-habitat of soil by complex mechanisms (Chen *et al.*, 1991).

Soil solarisation is a hydro-thermal process of natural disinfection of crop pathogens in the soil through the use of plastic sheets (usually transparent polyethylene (PE)) and passive heating by solar radiation during the warmest period of the year (Stapleton, 2000; D'Emilio *et al.*, 2012). Solarisation is caused by a combination of different physical, chemical and biological mechanisms and is compatible with other disinfection methods that achieve integrated pest control. This method replaces synthetic chemical disinfectants, and its use in greenhouses has increased globally as a result of the prohibition of methyl bromide in 2005, which was the most widespread chemical fumigant (Stapleton, 2000; Pivonia *et al.*, 2002), because of its dangerous effects on human health, destruction of the ozone layer and persistent residues in soil and water (United Nations Environmental Program (UNEP), 1992).

This prohibition promoted interest in the use of alternative techniques with low environmental impact for the control of soil pathogens and pests (Ros *et al.*, 2008), such as non-chemical methods (solarisation, steam and biofumigation), chemical methods (nematicide fumigant 1,3-dichloropropene, metam sodium, and carbamates, such as oxamyl) and biological methods (microorganisms).

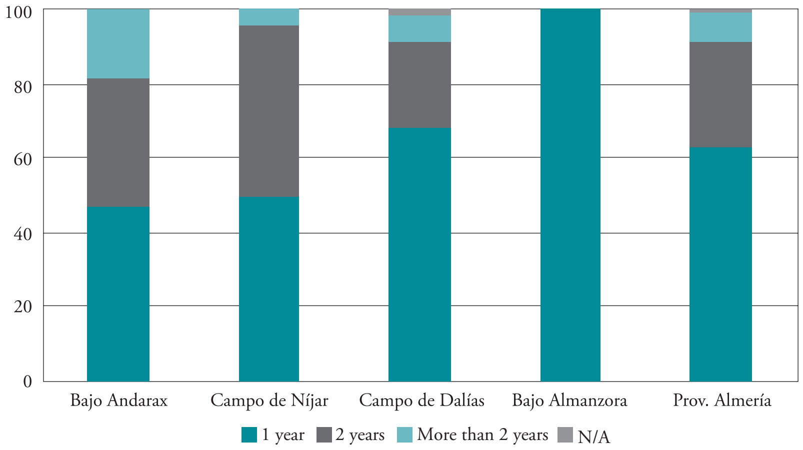
Although the execution of solarisation is simple, its action on the land is complex and involves a series of interconnected processes in treated soils that improve the sanitary state of the soil and growth, production, and quality of the crops (Katan *et al.*, 1987). The direct thermal deactivation of soil pathogens and pests is the most important mechanism in the solarisation process. Because solarisation is a passive method of heating the soil, temperatures reach their maximum during midday (Katan *et al.*, 1976). In the greenhouse, solar radiation generates lethal temperatures (> 50 ºC) during solarisation for the majority of soil pest pathogens (Streck *et al.*, 1996). In appropriate conditions, the effectiveness of this method reaches that of fumigation with methyl bromide (Gullino *et al.*, 1998). The solarisation effect can be augmented with the placement of a double layer of padding (Annesi and Motta, 1994; Ben Yephet *et al.*, 1987; Duff and Connelly, 1993; Salerno *et al.*, 1999), closure of the greenhouse during solarisation (Christensen and Thinggaard, 1999; Garibaldi and Tamietti, 1983; Horuichi, 1991; Mahrer *et al.*, 1987) and use of elevated solarising benches (Gullino *et al.*, 1998) or shallow layers of substrate in containers (Pivona *et al.*, 2002).

The efficiency of this technique depends mainly on the duration and intensity of the temperature increase, sensitivity of the pathogen, infection level of the soil (Tamietti and Valentino, 2006; Camprubi *et al.*, 2007; French-Monar *et al.*, 2007) and its integration with other pest control systems (Polizzi *et al.*, 2003; Minuto *et al.*, 2006; Oka *et al.*, 2007; Jayaraj and Radhakrishnan, 2008).

A recent alternative to the classic solarisation technique is biosolarisation, which consists of the combination of solarisation and biofumigation with volatile substances from bio-degraded organic matter (manure or industrial agricultural waste, such as sugar beet vinasse, lemon peel or rice husk). Biosolarisation has been used in pepper in greenhouses in Murcia (Spain), with reductions in the populations of Meloidogyne incognita (Ros *et al.*, 2008), Phytophthora (Lacasa *et al.*, 2010) and Fusarium (Martínez *et al.*, 2011) similar to or greater than those obtained by methyl bromide.

The frequency at which the famers of Almería conduct disinfections is 1 year in 63 % of the cases, 2 years in 28 %, and 3 years in 7.5 % (Figure 178). It is worth noting that in the Bajo Almanzora region, 100 % of the respondents disinfect each year. In the Bajo Andarax and Campo de Níjar regions, annual disinfection is performed in less than 46-47 % of the farms.

Figure 178. Frequency of soil disinfection. In percentage



Soil maintenance labour

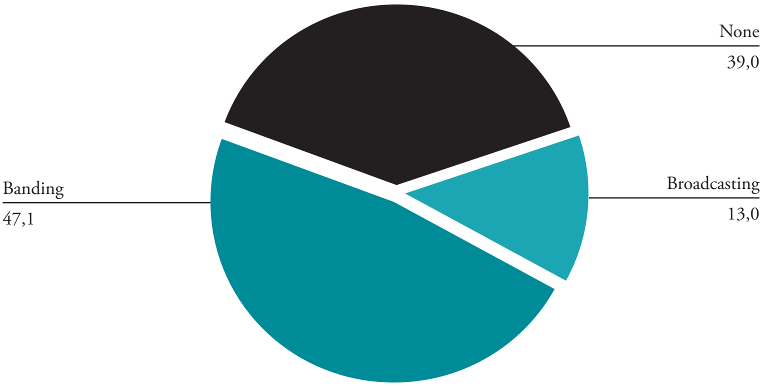
Labour for soil maintenance has increased in the last 16 years (Figure 179), and the number of greenhouses that did not require any type of maintenance labour has reduced from 56.5 % in 1997 to 39 % currently. An increase in manure broadcasting and banding (substitution of organic material below the crop lines) from 8.7 % to 47.1 % was observed, and the technique of broadcasting manure (replacement of cover fertiliser) over the entire greenhouse surface has been reduced, most likely to cut costs.

Broadcasting increases the duration of the agricultural qualities of sanded soil over the long term, and broadcasted soil is capable of absorbing a greater quantity of water than non-broadcasted soil. Although banding is a technique that permits considerable savings of material, time and manual labour, it leads to a degradation of sand plots and loss of yields compared with comprehensive broadcasting (Bretones, 2003).

In general, broadcasting has been reduced by almost a third in the greenhouses of the two main producing regions, Campo de Dalías and Campo de Níjar, and this technique has been altogether abandoned in Bajo Almanzora (Table 21). In Bajo Andarax, it was slightly reduced. In contrast, there has been a significant increase in the use of the banding technique, especially in Campo de Níjar.

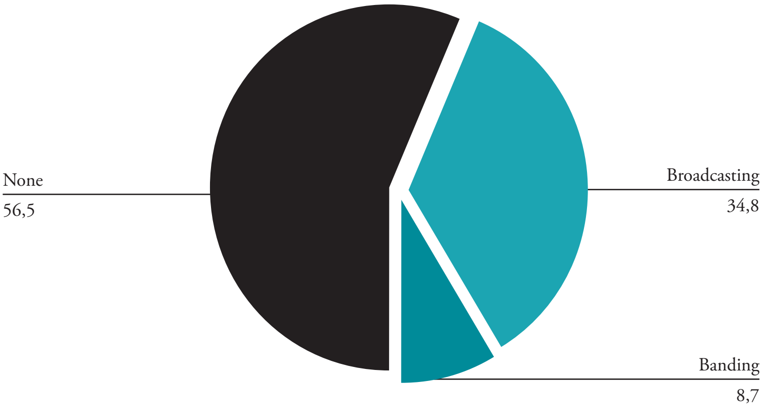
Figure 179. Evolution between 2013 (a) and 1997 (b) of soil maintenance labour in the greenhouses of Almería. In percentage

2013



Source: survey. Own elaboration.

1997



Source: Molina-Aiz (1997).

Table 21. Evolution of soil maintenance labour of greenhouses in different greenhouse regions between 2013 and 1997. In percentage

Region	Broadcasting		Banding		Broadcasting not performed	
Surveyed	**2013**	**1997**	**2013**	**1997**	**2013**	**1997**
Campo de Dalías	13,8	36,2	44,2	6,8	42,0	57,0
Campo de Níjar	11,1	36,7	60,0	12,0	24,4	51,3
Bajo Andarax	16,1	17,9	41,9	17,9	41,9	64,2
Bajo Almanzora	0,0	30,0	44,4	10,0	55,6	60,0

The results indicate that the majority of greenhouses in Almería utilise the traditional growing methods of the area (sanded soil with broadcasting or banding), and the importance of these techniques has increased in recent years. This fact lies in contrast to the earlier idea that production differences with other regions indicated a need for a technology change in Almería. Time has demonstrated that Almeria's production system is perhaps the most adapted one to the new sociocultural context required by European consumers, who demand a high-quality product at low environmental cost, which the greenhouses of Almería provide with great efficiency, as previously discussed (Section 2.17).

In the province of Almería, broadcasting is performed every 1-2 years in 39 % of the greenhouses (Figure 180), and the frequency of organic matter repositioning beneath the sand in the soil is 3-4 years in 40 % of the farms. In Campo de Dalías, the percentage of farmers that conduct broadcasting every 1-2 years is reduced to 33 %, which is substantially less than that in the other regions.

The type of organic matter used for broadcasting is predominantly sheep manure in 46 % of the greenhouses (Figure 181), which is an expected result since it is a by-product of the sheep livestock enterprises in the province of Almería. The second type most frequently used is organic material in prepared sacks, which represents 13 % of the greenhouses that perform broadcasting.

Compost is used in 7 % of the greenhouses, although in the Campo de Dalías region, its use is at 9 %. Equally notable is the fact that in Bajo Almanzora, the farmers that conduct broadcasting use mixes of different types of fertiliser.

The average cost of broadcasting is 30.9 €/m^3 for an application volume of 71.6 m^3 ha^{-1}, with similar values in the main productive regions of Campo de Dalías and Campo de Níjar (Figure 182) and somewhat lower values in the other two regions, where sheep manure is less frequently used (Figure 181).

Figure 180. Frequency at which farmers conduct broadcasting or banding. In percentage

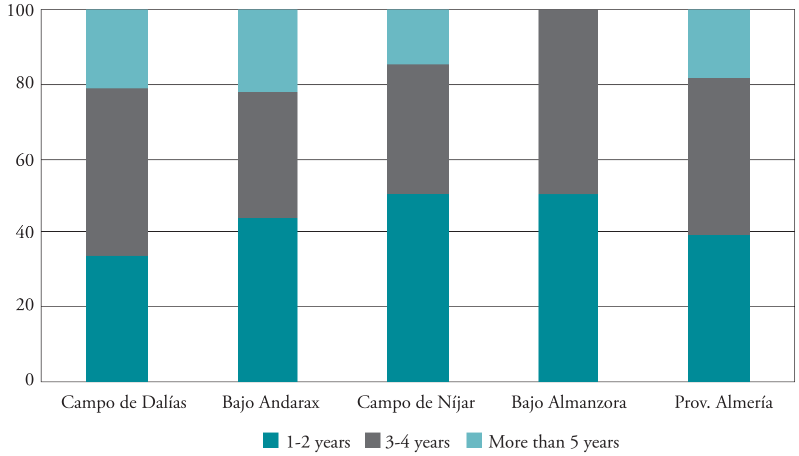
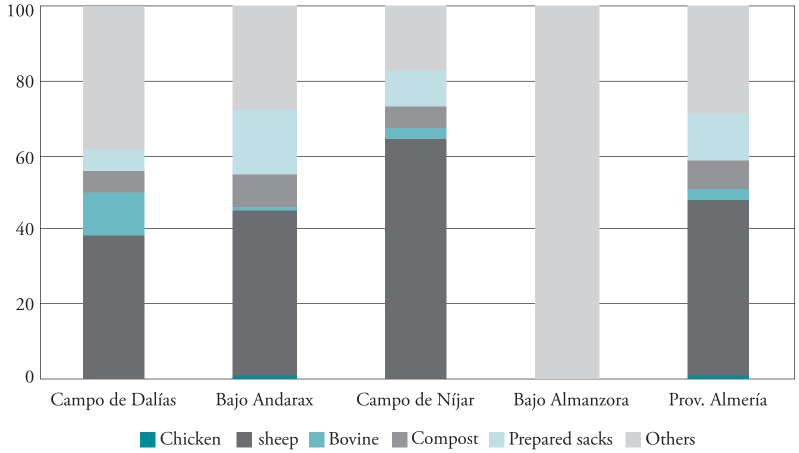
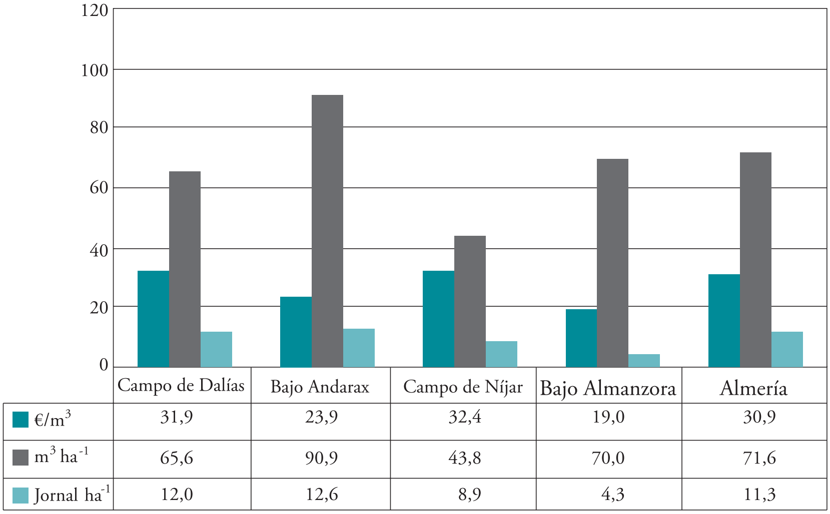


Figure 181. Type of organic matter used for broadcasting or banding*



** Other materials include fertiliser granules, horse and chicken manure, pig and sheep manure, pig and cow manure, coconut fibre, vermicompost and various mixtures.*

Figure 182. Labour costs for broadcasting, volume of organic material incorporated and labour wages per surface unit of greenhouse soil



	Campo de Dalías	Bajo Andarax	Campo de Níjar	Bajo Almanzora	Almería
■ €/m^3	31,9	23,9	32,4	19,0	30,9
■ m^3 ha^{-1}	65,6	90,9	43,8	70,0	71,6
■ Jornal ha^{-1}	12,0	12,6	8,9	4,3	11,3

The greatest volume of organic material is used in Bajo Andarax, 90.9 m^3 ha^{-1}, whereas the lowest is used in Campo de Níjar (43.8 m^3 ha^{-1}), which is likely related to the increased use of the banding technique in this area (60 % compared with 41.9-44.4 % in the other three regions) because this method requires a smaller volume of organic matter and is not conducted on greenhouse surfaces. In addition, wages for banding labour are lower in Bajo Almanzora, almost one third of the wages in Campo de Dalías and Bajo Andarax. In Campo de Níjar, lower wages are required to conduct broadcasting, which is possibly because of the importance and characteristics of banding.

The majority of surveyed farmers (89 %) add humic acids to condition the soil, with 100 % of the farmers in Bajo Almanzora adding humic acids (Figure 183).

Throughout the province, 91 % of the farmers are satisfied with the type of soil they use for their crops and have no intention of changing in the near future (Figure 184), whereas 6.6 % considered changing from traditional sanded soil («arenado») to soilless growing in substrate, and 1.8 % would change substrate for sanded soil, with these farmers residing entirely in Campo de Dalías (where they make up 3 %). In addition, 0.5 % would change from natural soil to sanded soil, which corresponds to 11.3 % of the greenhouses in Bajo Almanzora, where natural soil accounts for 66.7 % at present.

Figure 183. Percentage of farmers adding humic acids to soil by region. In percentage

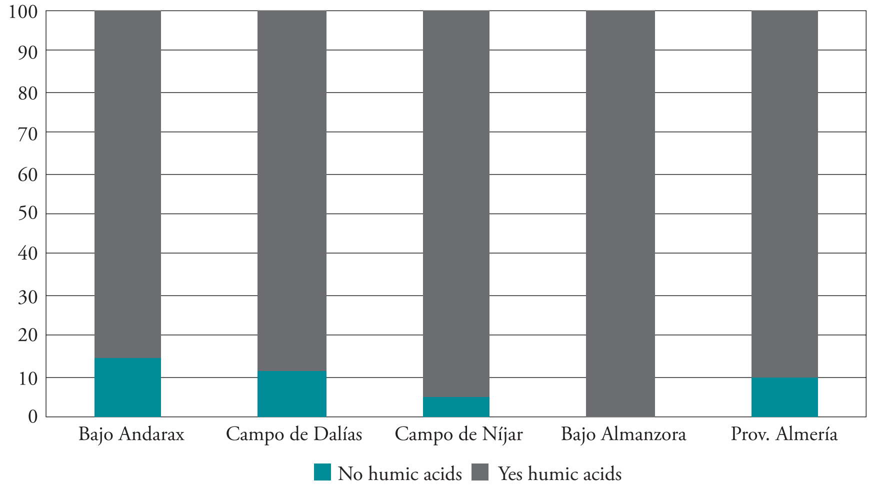
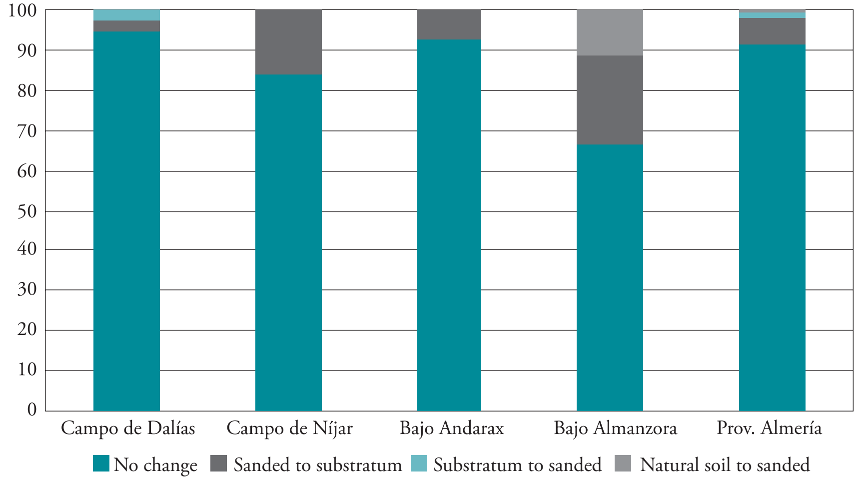


Figure 184. Percentage of farmers who have considered soil changes. In percentage



These data suggest that sanded crops are of good quality because farmers are satisfied with this soil and only a minority have considered changing. In addition, certain farmers who have replaced sanded soil with substrate have considered returning to sanded soil.

4.5. Auxiliary buildings and irrigation systems

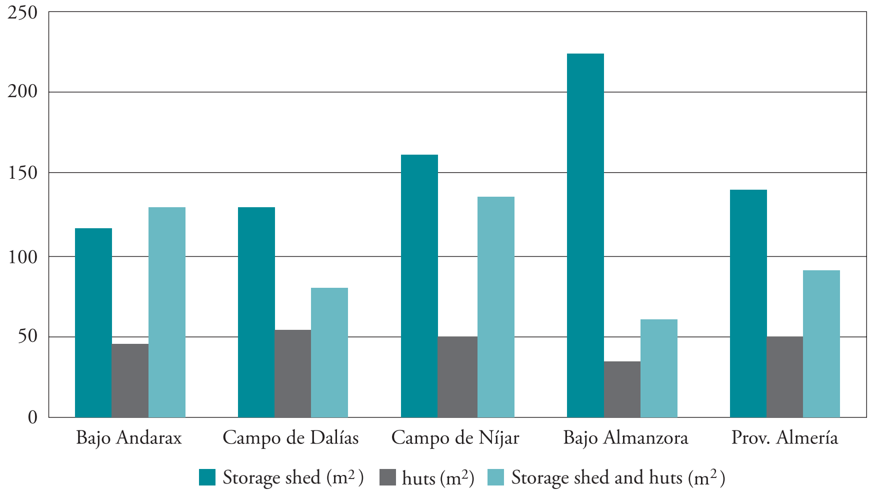
Traditional physical infrastructure for greenhouse crops includes a small storage area, hut for the irrigation head, and pond for water storage.

Storage areas and irrigation huts

In general, farmers use small storage units to maintain the necessary tools and machinery for horticultural labour, phytosanitary products, and harvested products before transportation to the markets. In certain cases, these storage areas include small refrigerators and simple gauge machines.

The average surface area of the storage areas in the province of Almería is 141 m^2 (Figure 185), and these structures range from small storage areas (10 m^2) for tools to large facilities (1,000 m^2). Regarding the distribution by region, Bajo Almanzora has the largest surface of storage areas, whereas Bajo Andarax has the smallest, and this difference may have been caused by factors such as the longer or shorter distances that separate the holdings from the companies that market the agricultural products, thus modifying the storage requirements for production before sale. In Bajo Andarax, the distance is short, and the famers can transport their products daily. Another factor is the size and number of greenhouses that are served by the storage areas.

Figure 185. Average surface of the storage areas and irrigation huts

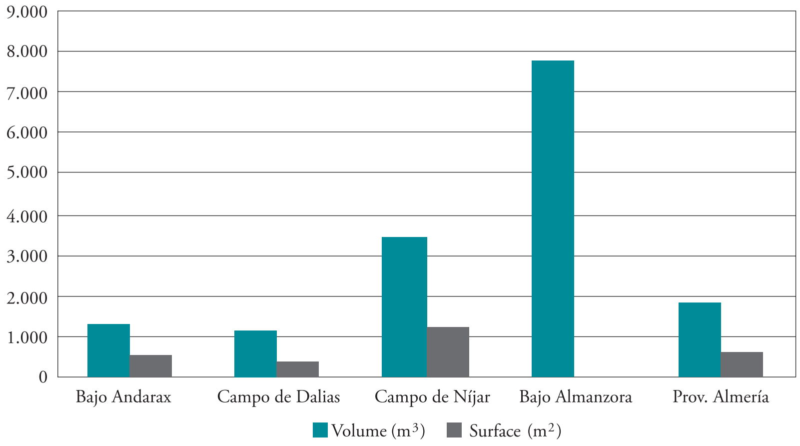


The irrigation huts have an average size of 50 m^2 and vary from 5 to 100 m^2 depending on whether the irrigation heads are for small greenhouses or provide service to a large number of structures. The irrigation hut may be included in the general storage area, and the average surface of such combinations is 91 m^2; this value is less than the surface of storage areas without huts and may be related to the greater storage needs in large holdings, which require more specific irrigation systems and specific irrigation huts.

Irrigation ponds

The majority of greenhouse holdings of Almería have a pond where water required for irrigation is stored for the greenhouses of each farmer. Large communal ponds for several farmers have also been constructed, and they have high storage volumes, which increases the variability of irrigation pond surfaces and volumes between regions (Figure 186).

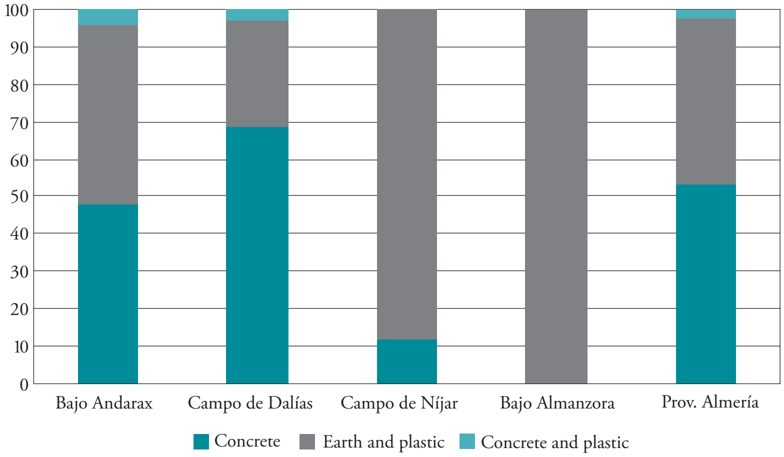
Figure 186. Average surface and volume of the irrigation ponds



In addition, the presence of large communal ponds with volumes from 10,000-30,000 m^3, such as in the Campo de Níjar and Bajo Almanzora regions, considerably increases the regional average value. Without considering large ponds greater than 10,000 m^3, the average volume for Campo de Níjar is 2,231 m^3 and for Bajo Almanzora is 262.5 m^3. However, the average depth of these ponds varies between 2.5 m and 3.2 m.

Material used to construct the irrigation ponds is predominately concrete (50 %), followed by earth using loose material covered with plastic sheeting (42 %). In addition, 2.2 % of the ponds are constructed of concrete and covered with plastic sheets to ensure their impermeability (Figure 187).

Figure 187. Construction material of the irrigation ponds. In percentage



A greater number of ponds constructed of plastic-covered earth can be observed in Campo de Níjar and Bajo Almanzora (Figure 187). This type of pond can be constructed for large capacities (greater than 5,000 m^3) and accounts for 14.6 % of the ponds in Campo de Níjar and 25 % in Bajo Almanzora.

The majority of ponds (85 %) are rectangular, square or cube shaped (Figure 188), with the remainder triangular and cylindrical. In Campo de Dalías, pond construction is primarily square shaped (32 %), whereas in Campo de Níjar, 77 % are rectangular, and in Bajo Almanzora, 40 % have a circular floor.

The majority of the farmers collect rain water for incorporation into the irrigation system, which provides economic savings and environmental benefits. Of these farmers, 47.5 % collect water from the roof of the greenhouse and 19 % recover water from the exterior (Figure 189). This increasingly entrenched custom also improves the quality of irrigation water and reduces the risk of damage by runoff.

Figure 188. Geometry of irrigation ponds. In percentage

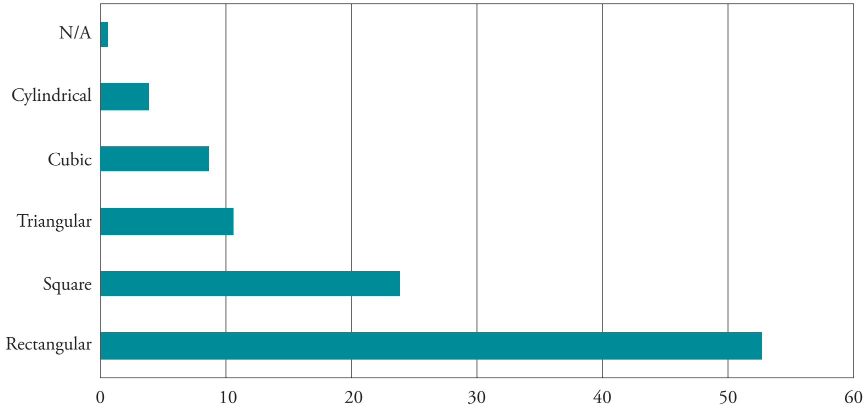
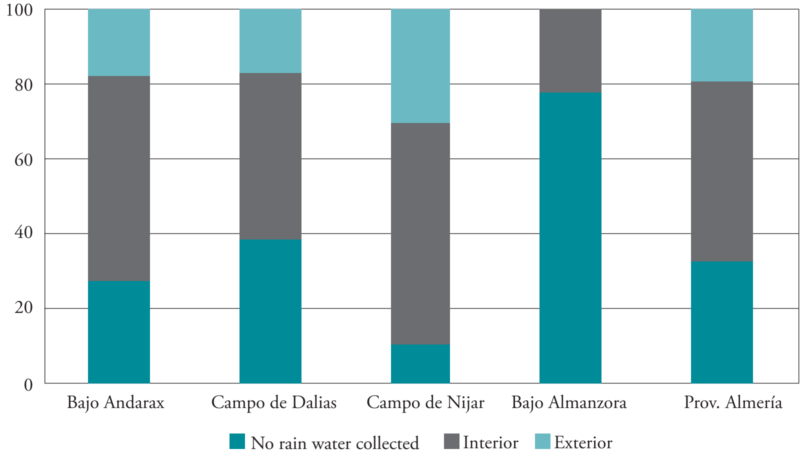


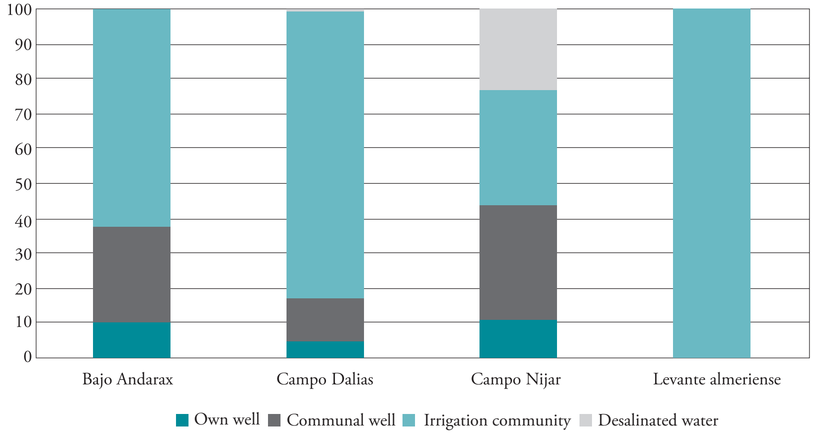
Figure 189. Percentage of farmers who collect rain water in the province of Almería



Origin, cost and characteristics of the water

The majority of surveyed farmers (70.8 %) use irrigation water from irrigation communities, with 100 % of farmers in the Bajo Almanzora region following this practice (Figure 190). In addition, 17.9 % of the farmers use irrigation water from communal wells belonging to different farmers, with 27.4 % in Bajo Andarax and 33.1 % in Campo de Níjar following this practice, which is partly caused by the higher conductivity of well water (Figure 191) increasing its suitability for growing tomato in these regions.

Figure 190. Origin of water used by farmers. In percentage



Similarly, the farmers of those regions use their own well water: 10.2 % in Bajo Andarax and 10.9 % in Campo de Níjar, accounting for 6.3 % of the entire province. Water obtained in this manner has a high electrical conductivity (between 2.8 and 6.5 dS m^{-1}), and the farmers of Bajo Andarax who use this source of water mix it in almost equal proportions (46 %) with water from irrigation communities, which has lower conductivity at approximately 2 dS m^{-1} (Figure 191).

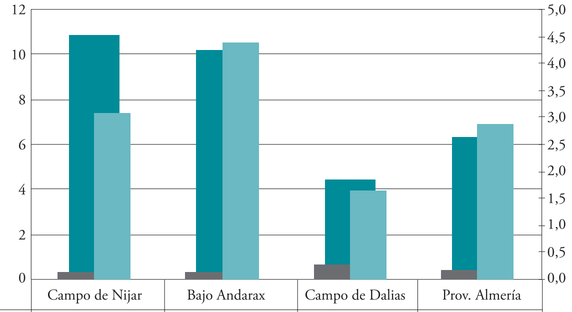
In addition to its high conductivity for growing tomato, water from self-owned wells reduces costs because the average price of well water in Campo de Níjar and Bajo Andarax is between 0.12 and 0.13 €/m^3, which is lower compared with the prices of water from irrigation communities or community wells at 0.31-0.39 €/m^3 (Figure 191).

It is also noteworthy that water originating from the wells of Campo de Dalías has an average electrical conductivity of 1.6 dS m^{-1}, which is much less than that of the other regions and is also lower than that of the irrigation communities. Water with the lowest salinity corresponds to the irrigation communities of Campo de Níjar (1.0 dS m^{-1}), which may be a result of the contribution of water from the Carboneras desalination plant (Almería).

The majority of farmers (82.5 %) conduct analyses of the irrigation water to control its quality (Figure 192). Farmers perform the fewest water analyses in Campo de Dalías (77 %).

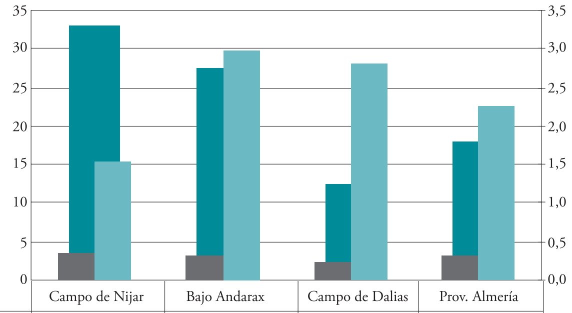
Figure 191. Percentage of mixed water from own wells (a), communal wells (b) and irrigation communities (c); the cost of water and its electrical conductivity are also indicated for each region and the entire province

a)



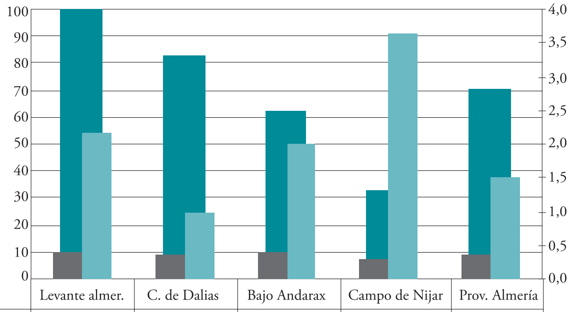
	Campo de Nijar	Bajo Andarax	Campo de Dalias	Prov. Almería
■ Farm well (%)	10,9	10,2	4,5	6,3
■ Cost (€/m^3)	0,1	0,1	0,3	0,2
■ Electrical conductivity (dS/m^3)	3,1	4,4	1,6	2,9

b)



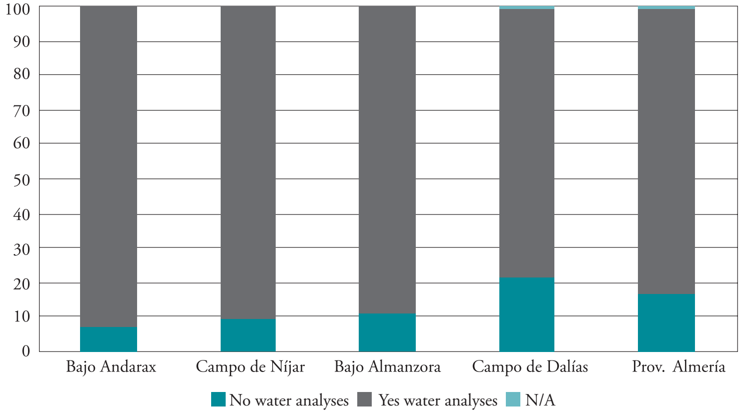
	Campo de Nijar	Bajo Andarax	Campo de Dalias	Prov. Almería
■ Farm well (%)	33,1	27,4	12,4	17,9
■ Cost (€/m^3)	0,4	0,3	0,2	0,3
■ Electrical conductivity (dS/m^3)	1,5	3,0	2,8	2,3

c)



	Levante almer.	C. de Dalias	Bajo Andarax	Campo de Nijar	Prov. Almería
■ Irrigation community (%)	100,0	82,6	62,4	32,9	70,8
■ Cost (€/m^3)	0,4	0,4	0,4	0,3	0,4
■ Electrical conductivity (dS/m^3)	2,2	1,0	2,0	3,7	1,5

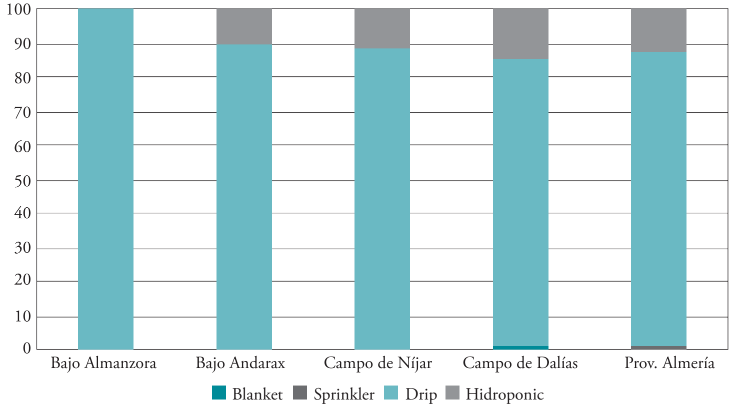
Figure 192. Analysis of irrigation water. In percentage



Irrigation system

A fundamental element in greenhouse management is fertigation equipment that supplies water and nutrients to the plants and can be controlled by adjusting the dosage according to crop requirements. Almost all the farmers have localised irrigation (99.6 %), including drip irrigation on sand plots (85.8 %) or hydroponic crops in substrate (12.9 %). Only 0.4 % of the farmers use flood irrigation (Figure 193). This low number implies that substantial technological improvements have been made in the region because this technique, which is inefficient in the use of water, was used in 4.9 % of the greenhouses in 1997.

Figure 193. Irrigation system used. In percentage



Irrigation control

Tensiometers constitute a simple system to control irrigation by measuring the hydric potential of soil. This system is employed by 57 % of the farmers, although only 11 % employ this technique in Bajo Almanzora, whereas the other regions are similar to the provincial average (Figure 194).

Currently, 81 % of the surveyed farmers have automatic irrigation controllers to manage fertigation (Figure 195), which has been one of the greatest technical advances in greenhouses of Almería over the past 16 years because, in 1997, only 22.6 % of farmers used this type of equipment. The controllers are the least used in the Bajo Almanzora region (67 %) followed by Campo de Dalías (79 %), with the remaining two regions at 86 %.

Figure 194. Use of tensiometers for irrigation control. In percentage

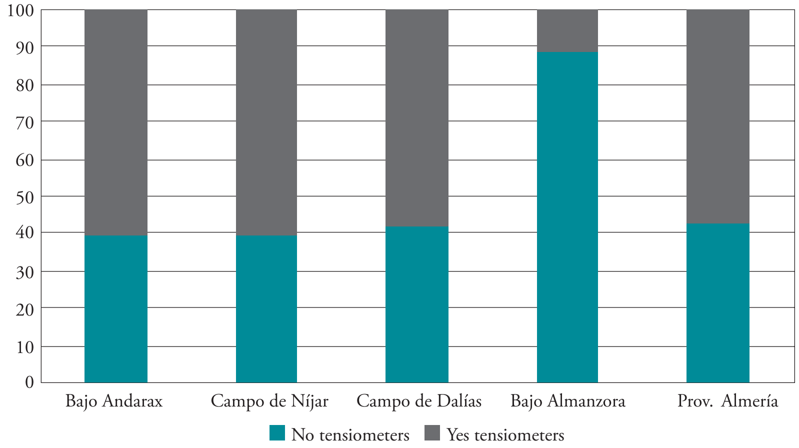
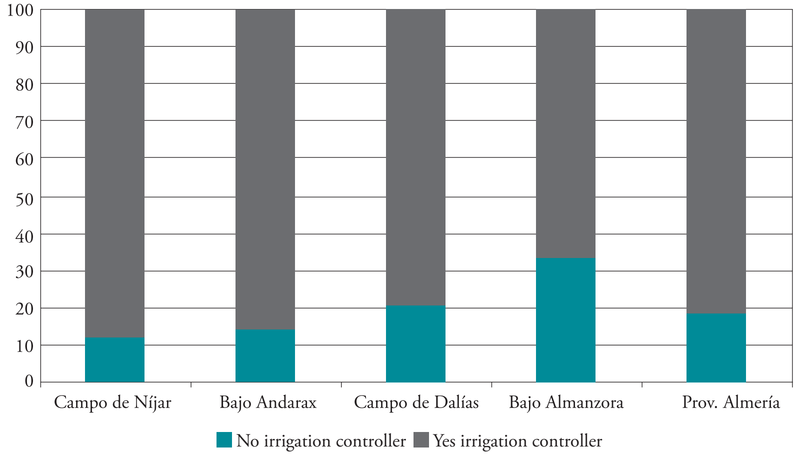


Figure 195. Utilisation of automatic irrigation by farmers in Almería. In percentage

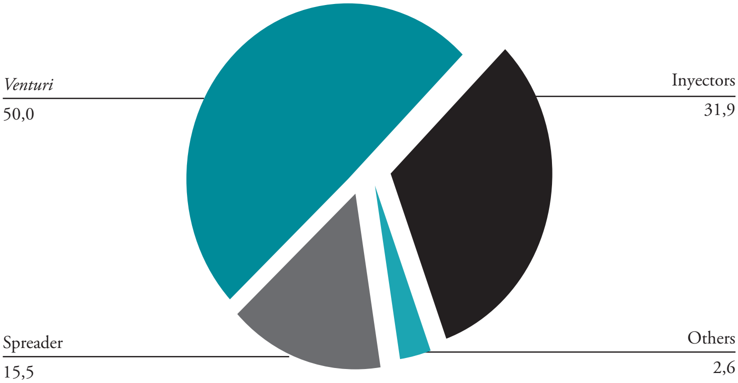


Currently, only a minority of farmers utilise spreaders without electronic control (15.5 %), although this system was commonly used 16 years ago (77.4 %). Irrigation controllers in 1997 were based on Venturi systems and injectors in similar proportions (Figure 196b), whereas half the farmers of Almería currently use fertigation equipment with the Venturi system (Figure 196a).

An analysis of the evolution of fertigation systems by region shows that Bajo Almanzora has experienced the smallest increase in the number of automated systems relative to the amount in 1997 (Table 22). Compared with the other three regions, Bajo Almanzora has a greater number of installations with injector systems (40 %) than Venturi systems (20 %). In Campo de Dalías and Bajo Andarax, the use of spreaders is still important and accounts for 18.7 % and 10.7 % of the farms, respectively, whereas in Campo de Níjar, their use is nominal (2.3 %).

Figure 196. Evolution between 2013 (a) and 1997 (b) of fertigation systems used by farmers in the greenhouses of Almería. In percentage

2013 (a)



Source: survey. Own elaboration.

1997 (b)

Source: Molina-Aiz (1997).

Table 22. Evolution of fertigation systems used by farmers in the different greenhouse regions between 2013 and 1997. In percentage

Region	**Spreaders**		***Venturi***		**Injectors**	
Surveyed	**2013**	**1997**	**2013**	**1997**	**2013**	**1997**
Campo de Dalías	18,7	72,1	46,7	13,6	31,3	14,3
Campo de Níjar	2,3	88,9	61,4	1,9	34,1	9,2
Bajo Andarax	10,7	87,2	60,7	10,3	28,6	2,5
Bajo Almanzora	40,0	100,0	20,0	0,0	40,0	0,0

The majority of farmers use their own pump for irrigation (Figure 197), and farmers that lack pumps have installations that receive water from distribution networks of irrigation communities or have sufficient pressure for the functioning of fertigation equipment.

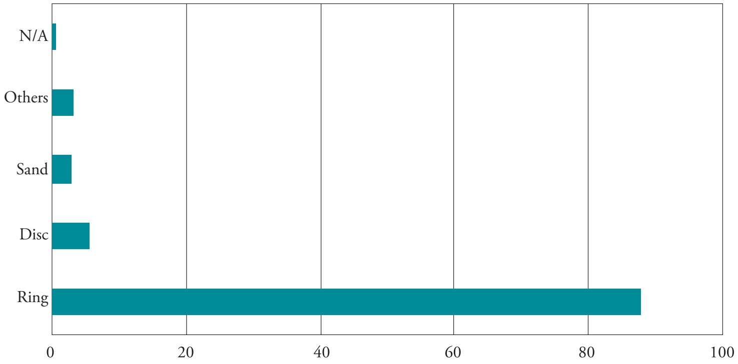
The main type of pump installed (97.8 %) in greenhouses throughout the province is electric, which has an average power of 5.5 kW (Table 23); this type of pump is the only type of propulsion used in the Campo de Níjar and Bajo Andarax regions. In Bajo Almanzora, 14.3 % use diesel pumps, with an average power of 10.3 kW.

Table 23. Pump type used with irrigation systems and average power

Region	**Electric**	**Power (kW)**	**Diesel**	**Power (kW)**
Campo de Dalías	97,4	5,7	2,6	7,4
Campo de Níjar	100,0	5,4	0,0	
Bajo Andarax	100,0	4,9	0,0	
Bajo Almanzora	85,7	3,9	14,3	10,3
Province of Almería	97,8	5,5	2,2	7,9

The majority of surveyed farmers use ring filters in the fertigation system (87.9 %), with the disc and sand filter types being the most popular (Figure 198). Sand filters are used in Bajo Andarax, where 17 % of the greenhouses utilise this type of irrigation filter. Disc filters are most frequently used in Campo de Níjar, accounting for 9 % of the irrigation installations.

Figure 198. Types of filters used in irrigation systems. In percentage



4.6. Marketing

Another aspect that characterises the Almería greenhouse production system is the way in which agricultural products are marketed. These considerations have a strong influence on the way that farmers work because in many cases the companies that market the agricultural products also provide farmers with technical advice, impose work protocols based on quality standards, and even plan crop distributions.

Type of organisations that market agricultural goods

The surveyed farmers are divided equally among cooperatives (40 %) and Sociedades Agrarias de Transformación or SAT, a special type of civil society for the production, processing and marketing of agricultural goods (38 %); with a smaller proportion of farmers selling their products in Alhóndigas, or agricultural trading and bidding firms (17 %) and an even smaller proportion (4 %) selling their products using private marketers (Figure 199).

In addition, the majority of surveyed farmers (92 %) market their products through a single entity (Figure 200).

The majority of surveyed farmers are partnered with organisations that market their agricultural products (72.6 %), with more than half (51.4 %) having been partnered for more than 10 years (Figure 201). In Campo de Níjar, the percentage of associates is greater (81.4 %), with the percentage varying slightly in the other three regions between 66.7 % and 71.4 %.

In addition, 98.5 % of the surveyed farmers receive technical advice, which is similar to 1997 (Figure 202).

Figure 199. Type of organisations used by farmers to sell their production. In percentage

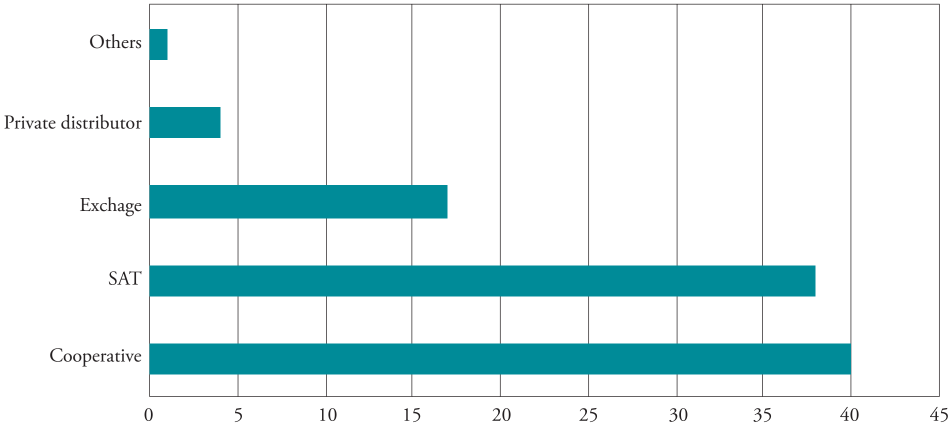


Figure 200. Fidelity of farmers to organisations. In percentage

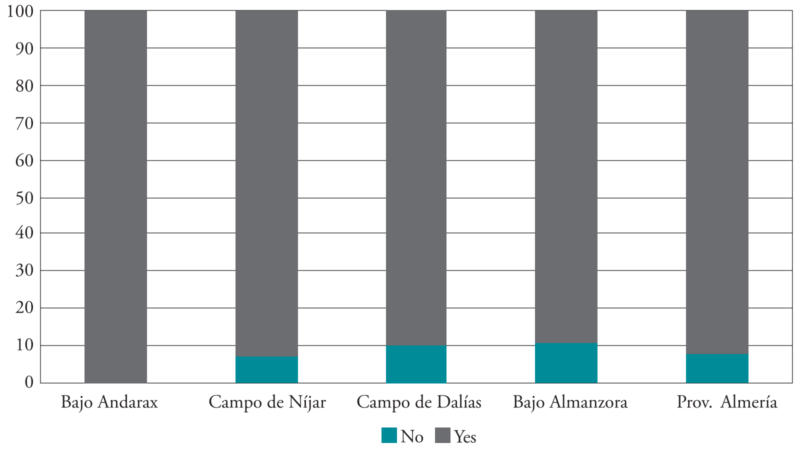


Figure 201. Percentage of farmers associated with organisations as a function of their age. In percentage

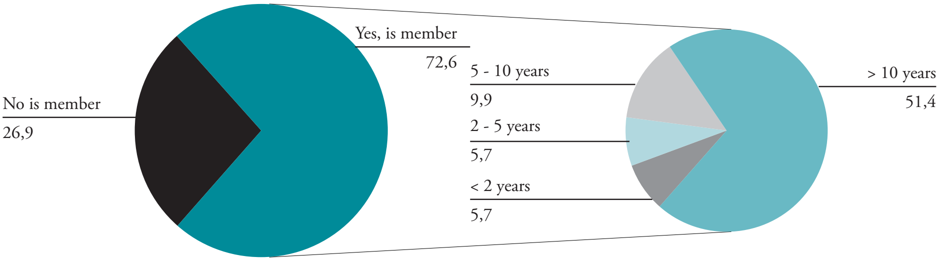
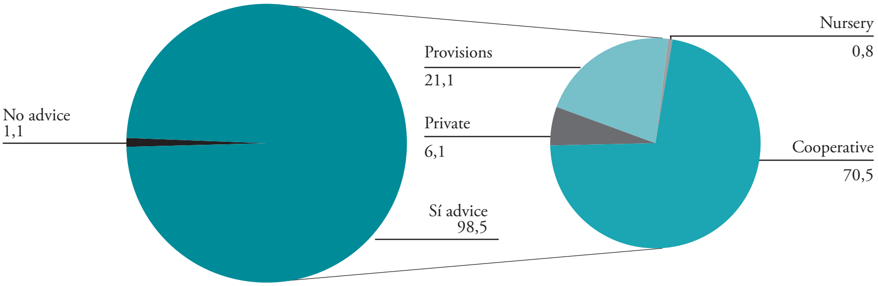


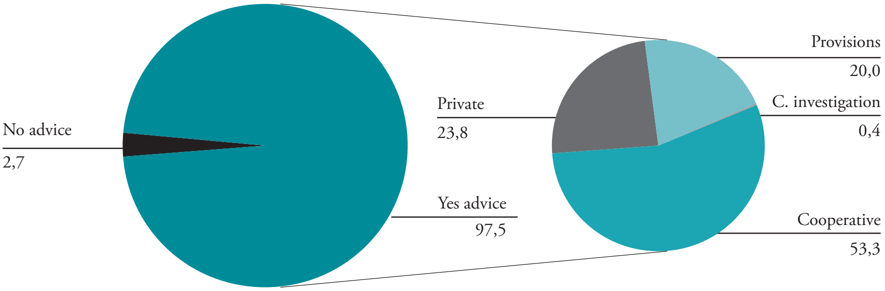
Figure 202. Evolution of the type of advice that farmers receive. In percentage

2013



Source: Survey. Own elaboration.

1997



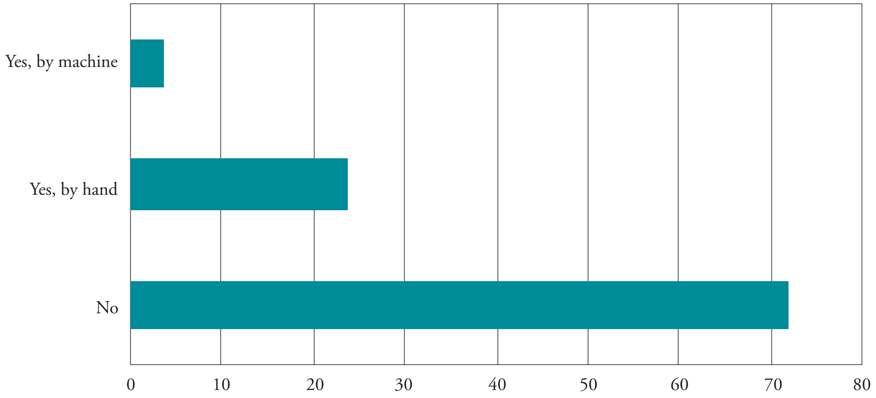
Source: Molina-Aiz (1997).

The main change is the increase in advice by cooperatives, which has reached 70.5 %, and the decrease in advice by private advisors, which was 23.8 % in 1997 and is only 6.1 % today.

Conditioning of the production and quality standards

In 2013, 72 % of the surveyed farmers reported that they do not directly prepare their products for sale (Figure 203), which corresponds with the approximately 78 % (Figure 199) who market their product through cooperatives or SAT, which have automated systems and can manage large-scale production using gauges and automatic packers. However, 24 % of farmers manually select, calibrate and place their products in boxes (40 % in Bajo Andarax), whereas 4 % do this with small gauge machines for tomatoes, with this number concentrated in the regions (Bajo Andarax, 20 %, and Campo de Níjar, 5 %) that specialise in the production of tomato.

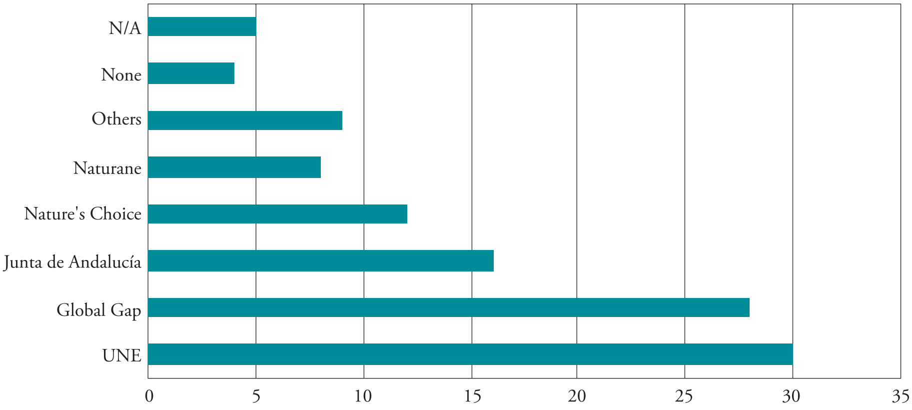
Figure 203. Product conditioning by farmers. In percentage



The majority of surveyed farmers (91 %) comply with certification systems or standards of good agricultural field practices (Figure 204), including the set of standards UNE 155001 «Fruits and vegetables for fresh consumption. Controlled production of protected crops» (30 %), good agricultural practices (GAP) standards (28 %), integrated production standards of the Regional Government of Andalusia (16 %), Tesco's Nature's Choice (12.2 %) and Naturane standards (8 %). Other standards that the farmers follow are

BRC, Agrocolour, GRAP, QS and ISO 9000. The farmers are subjected to various standards, and on average, they comply with two standards.

Figure 204. Certification systems or standards of good agricultural field practises. In percentage



4.7. Structural characteristics of the greenhouse

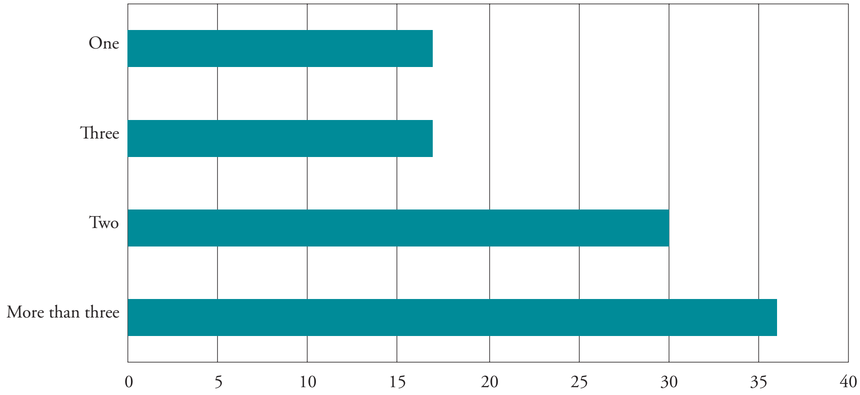
The most important element of the agricultural holding is the greenhouse, and its importance is a function of its construction and design characteristics, which influence the productive potential of crops throughout its useful life (as a function of the greenhouse's capacity to transmit solar radiation or for natural ventilation). In certain cases, the greenhouse structure can also limit the application of different technologies.

Number and typology of greenhouses in the holding

The majority of surveyed farmers have more than one greenhouse (83 %), and a greater proportion have more than three (Figure 205). None of the surveyed farmers in Bajo Almanzora have only a single greenhouse, and in Campo de Níjar, only 2 % have a single greenhouse, whereas the majority (65 %) own more than three greenhouses.

The main technological change with respect to the structure of greenhouses produced in Almería has been the change from traditional flat-top greenhouses (parral) to the raspa y amagado Almería-subtype greenhouses (Figure 206). Flat-top greenhouses produce microclimate deficiencies, such as excess humidity and temperature. In contrast, raspa y amagado greenhouses offer better performance and lower costs compared with multi-span greenhouses or Venlo-type greenhouses.

Figure 205. Number of greenhouses owned by surveyed farmers. In percentage

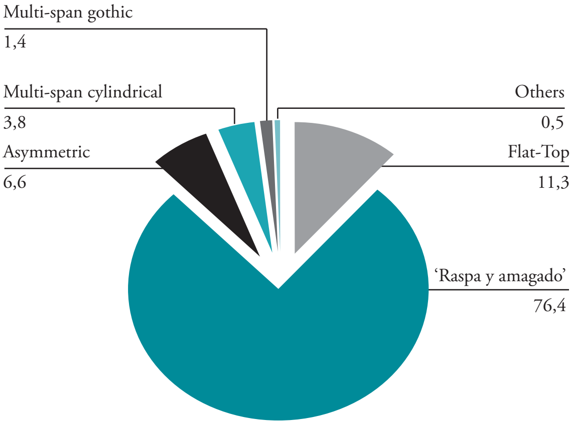


In addition, the percentage of asymmetric Almería-type greenhouses that have remained unchanged over time is between 2.4 % and 3.3 %, and recently, this number has increased to 6.6 % of the total.

In the province, the Almería-type greenhouses («flat», «raspa y amagado» and «asymmetric») accounted for 94.3 % of the total, which is similar to the 95.4 % installed in 1997. Mesh-covered, gabled, and Venlo greenhouses represent a small percentage primarily because these structures are expensive or implemented in restricted areas of the province, which occurs with mesh-covered greenhouses because they are mainly constructed in the Bajo Almanzora region. In the case of the gabled greenhouses, they are structures that were once popular but are no longer constructed.

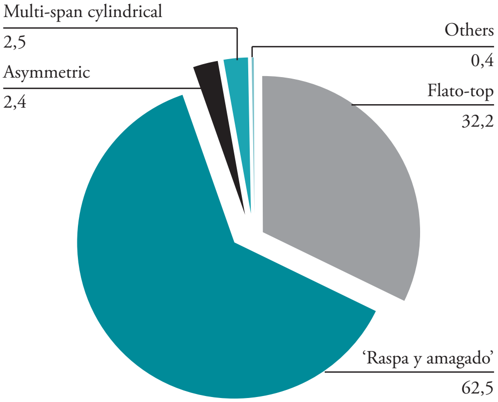
Figure 206. Evolution of greenhouse types over the past 16 years. In percentage

2013



Source: survey. Own elaboration.

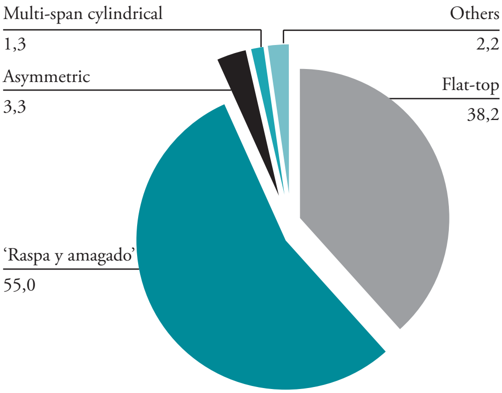
2006



Source: Junta de Andalucía (2006).

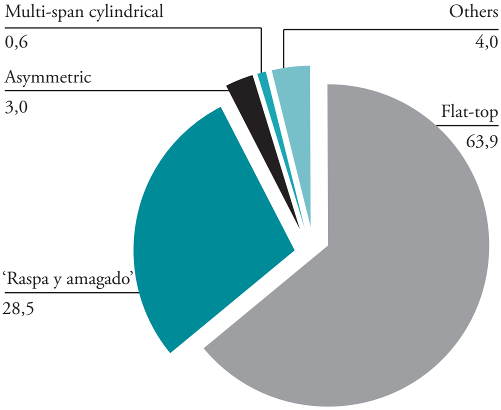
Figure 206 (cont.). Evolution of greenhouse types over the past 16 years. In percentage

2004



Source: Fernández y Pérez Parra (2004).

1997



Source: Molina-Aiz (1997).

The increase in multi-span greenhouse construction has been continuous and sustained; in 1997, 0.6 % of the greenhouses were multi-span, whereas today, the number is at 5.2 % (1.4 % of the gothic type). This increase has mostly been concentrated in Campo de Níjar, where this structure type currently constitutes 18.7 % of the greenhouses. This result is in contrast with the

Bajo Andarax and Bajo Almanzora areas, where none of the interviewed farmers reported owning this type of greenhouse, similar to the value in 1997 (Table 24). In addition, the percentage of asymmetric-type greenhouses is greater in Bajo Andarax and Bajo Almanzora than in the other three regions.

Table 24. Evolution of the percentages of different types of greenhouses in the regions sampled in 2013 and 1997

Region	Flat-top	Raspa y amagado	Asymmetric	Cylindrical Multi-span	Gothic/Gabled*	Screened
2013						
Campo de Dalías	15,2	75,8	6,1	1,5	0,8	0,8
Campo de Níjar	0,0	79,1	2,3	14,0	4,7	0,0
Bajo Andarax	14,3	75,0	10,7	0,0	0,0	0,0
Bajo Almanzora	0,0	77,8	22,2	0,0	0,0	0,0
Prov. of Almería	**11,3**	**76,4**	**6,6**	**3,8**	**1,4**	**0,5**
1997						
Campo de Dalías	64,2	29,2	3,5	0,4	2,7*	0,0
Campo de Níjar	64,2	30,4	1,8	1,8	1,8*	0,0
Bajo Andarax	71,8	15,3	2,6	0,0	10,3*	0,0
Bajo Almanzora	23,1	30,7	0,0	0,0	23,1*	23,1
Prov. of Almería	**63,9**	**28,5**	**3,0**	**0,6**	**3,6***	**0,4**

The reduced construction of flat-type greenhouses has been widespread throughout the province, highlighting its complete disappearance from the surveys conducted in Campo de Níjar and Bajo Almanzora.

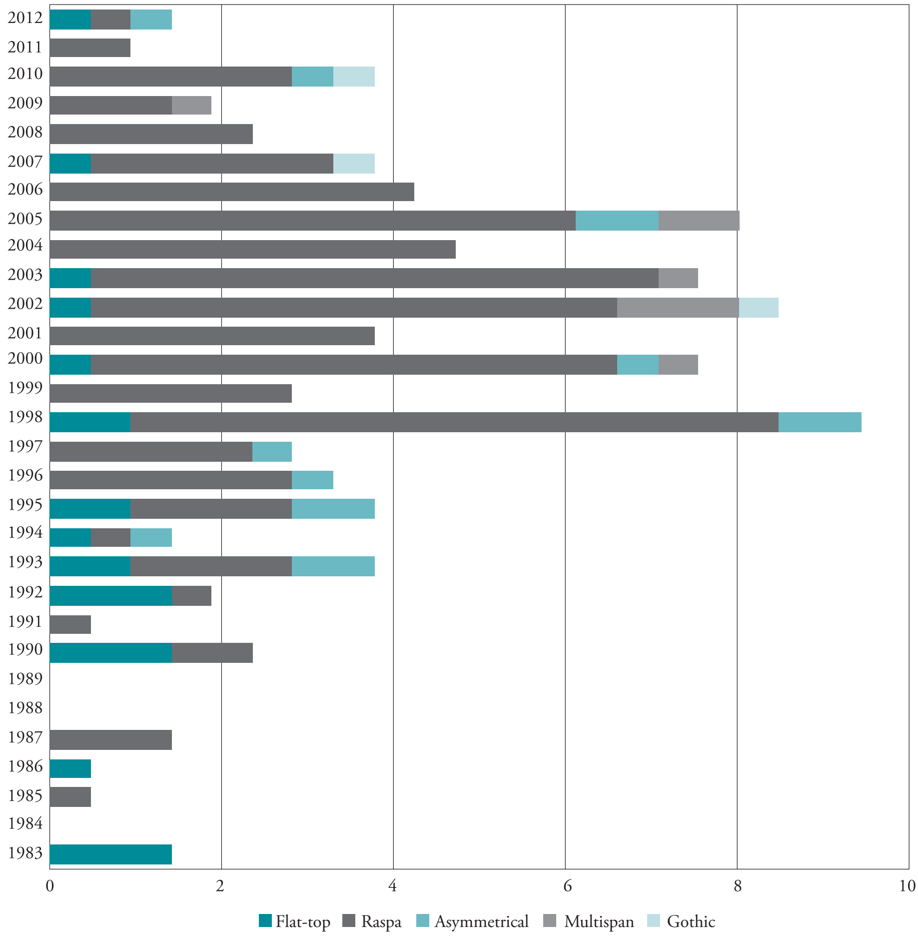
Differences in evolution between the two main production regions are also notable. In 1997, Campo de Dalías and Campo de Níjar had similar distributions of flat and raspa y amagado type greenhouses; however, nearly 15.2 % of the greenhouses in Campo de Dalías are currently the flat type (old with low performance), whereas a similar proportion (14 %) of greenhouses in Campo de Níjar are now of the multi-span type (modern with better performance).

Age and cost of the greenhouse

The average age of greenhouses today is greater than 12.7 years, and since the beginning of the 1990s, greenhouses have experienced a strong increase in surface (Figure 207). In addition, many of the previously constructed greenhouses have been renovated or replaced by new structures, and in some cases, they have been abandoned.

Figure 207. Year of construction of the greenhouses of the surveyed farmers in 2013 (a) and 1997 (b). In percentage

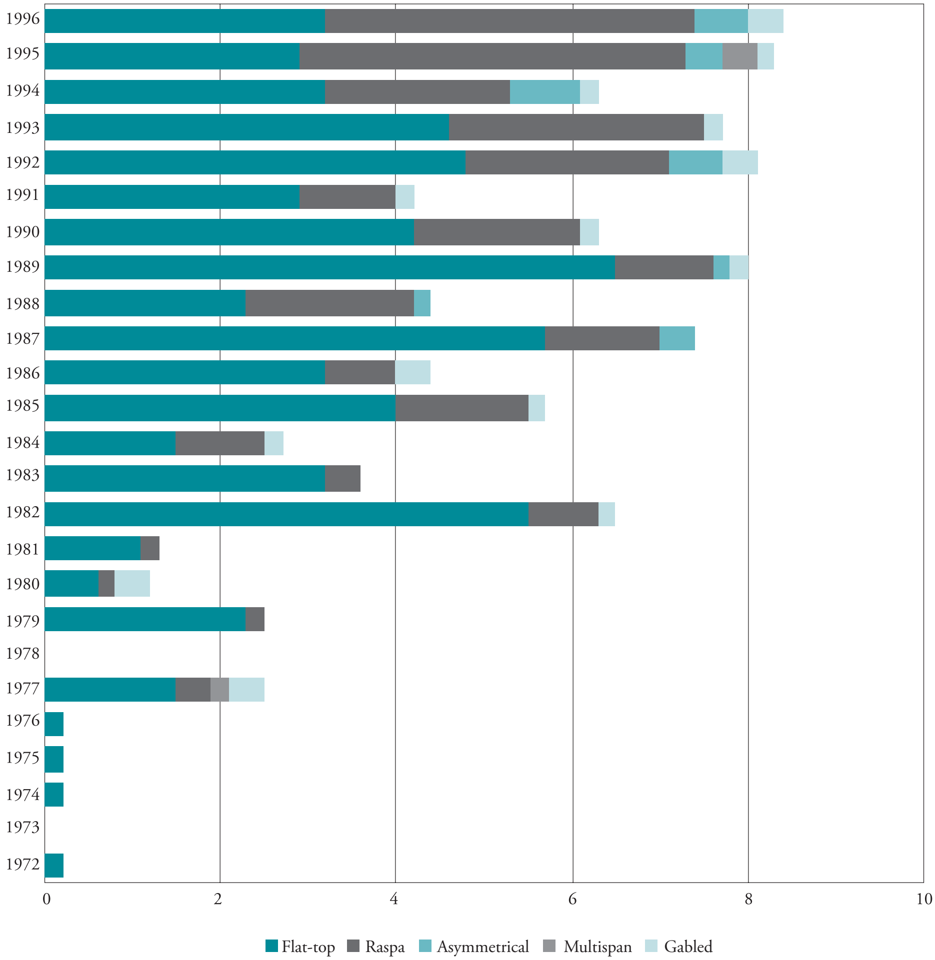
2013 (a)



The results from the recent interviews (Figure 207a) and interviews in 1997 (Figure 207b) show how the construction rate of greenhouses in Almería increased from the 1970s until the end of the last century and also indicate that their construction rate began to decrease at the end of the 1990s.

In 1997, new greenhouses predominated, and the average age was 8.1 years (4.6 less than the current average). Both surveys also show how the majority of greenhouses built from 1995 onwards are of the Almería-type and raspa y amagado subtype, which confirms the gradual increase of this structure to the detriment of flat-tops, which are no longer constructed.

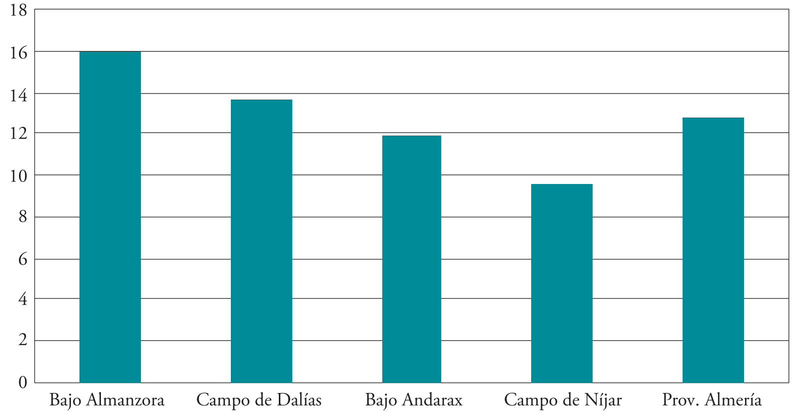
1997 (b)



New greenhouses often replace old structures, such as the majority of structures built before 1990, which were the flat subtype. The renovation of these obsolete structures is necessary because there is practically no new land for construction, and new greenhouses are built on plots previously used for greenhouses. This lack of land for construction is one of the reasons for the aging of greenhouses; in addition, current economic conditions greatly hinder the process of renewal of the structures and often lead to the maintenance or abandonment of inefficient structures and a lack of replacement with structures with greater productive capacity (raspa y amagado greenhouses, which have greater height and are equipped with roof windows in all the ridges).

An analysis of greenhouse age by region shows that the oldest structures are in Bajo Almanzora, with an average age of 16 years (Figure 208), which is in contrast with what was observed in 1997 when the age of the greenhouses in this area showed no differences compared with the other regions (Table 24).

Figure 208. Average age of greenhouses by region. In ages



The average age of the greenhouses of the Campo de Níjar region has only increased by approximately one year compared with that of 1997; this result is explained by the greater structure renewal in this region, where the construction costs are highest because of the increased presence of multi-span greenhouses (19 %, including gothic and cylindrical covered), which are more than double the price of Almería-type greenhouses (Table 25). In the case of gothic greenhouses, their average price rises to three times the average cost of a raspa y amagado greenhouse, which explains the limited expansion of these types of structures in the province.

The most modern types of greenhouses are the gothic type, followed by the multi-span-type (Table 25). Asymmetric greenhouses are, on average, older than the raspa y amagado type, although in the past three years, asymmetric greenhouses have made a strong comeback (Figure 206a).

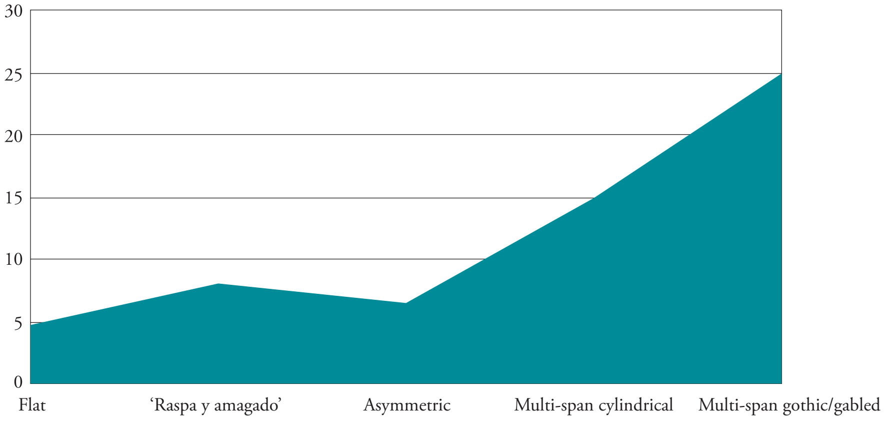
When examining the cost of greenhouses by region (Table 25), there is a correlation with the presence of multi-span type greenhouses (Table 24), which are much more expensive than the other structures (Figure 209).

Table 25. Cost, age, and orientation of the greenhouses by type and region and a comparison with data from 1997

Greenhouse/Regions	Cost (€/m^2)	Age	N-S	E-W	Age	N-S	E-W
		2013			1997		
Flat	4,7	19,6	75,0	20,8	9,1	34,2	28,6
Raspa y amagado	8,0	11,8	81,5	16,7	6,1	30,1	30,8
Asymmetric	6,4	13,6	21,4	78,6	4,4	25,0	31,3
Multi-span cylindrical	15,0	9,5	87,5	12,5	8,0	33,3	0,0
Multi-span gothic/gabled	25,0	6,7	100,0	0,0	9,4	23,5	29,4
Campo de Dalías	8,4	13,7	79,5	18,9	8,0	38,8	30,0
Campo de Níjar	9,1	9,6	76,7	20,9	8,7	10,1	21,1
Bajo Andarax	7,0	11,9	75,0	21,4	7,9	41,0	35,9
Bajo Almanzora	5,8	16,0	44,4	55,6	8,5	0,0	58,3
Province of Almería	**8,3**	**12,7**	**76,9**	**21,2**	**8,1**	**32,2**	**29,2**

* *Dates of multi-span gothic for to 2013 and gabled for to 1997.*

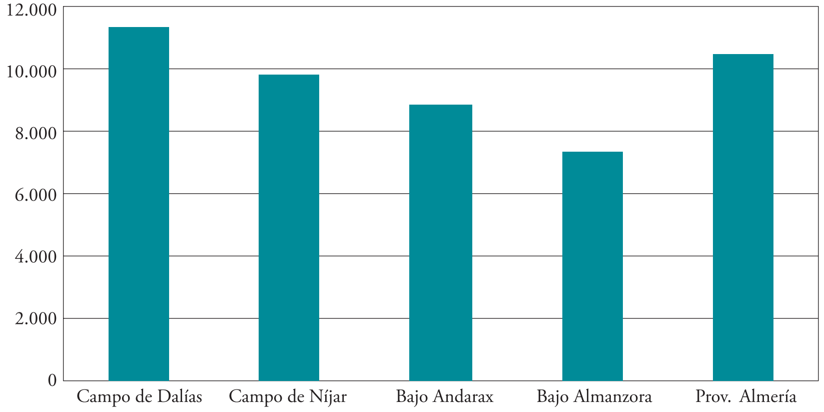
Figure 209. Approximate cost of greenhouse construction according to structure type. In €/m^2



Surface and geometry of the greenhouse

The average surface of the surveyed greenhouses was 10,503 m^2 (Figure 210), and the width and length were 76.9 m and 136.3 m, respectively (Table 26). These values are considerably greater than those of 1997, when the greenhouse surface for the entire province was 6,457 m^2, with an average width of 52.5 m and length of 124.9 m.

Figure 210. Greenhouse average surface. In m^2



Another aspect to consider with respect to the evolution of structures is the considerable increase of greenhouse height from an average of 2.9 m in 1997 to 4.4 m today (Table 26). The increase is observed in all types of greenhouses, with a value of 1-1.1 m in Almería-type greenhouses, excluding the flat type, which has only increased 0.4 m, although the reduction is related to the obsolescence of lower greenhouses and not to the construction of higher ones. In the case of multi-span greenhouses, increasing height has been even more considerable, with increases of 2.1 m on average.

Of the farmers surveyed, 17 % have increased the height of their greenhouse by replacing the mostly wooden supports of Almería-type structures for longer ones that are generally composed of galvanised pipes.

The increase in the greenhouse surface and height has produced a dramatic increase in the unit volume, surpassing the average value in 1997 of 17,186.7 m^3, with a current average of 42,293.3 m^3, which is 2.4 times greater. The increase in the amount of air confined in the greenhouse improves the internal microclimate by increasing thermal inertia and facilitating air movement above the crop.

Table 26. Geometric characteristics of the greenhouses (Figure 211) in the surveys conducted in 2013 and 1997*

Survey of 2013

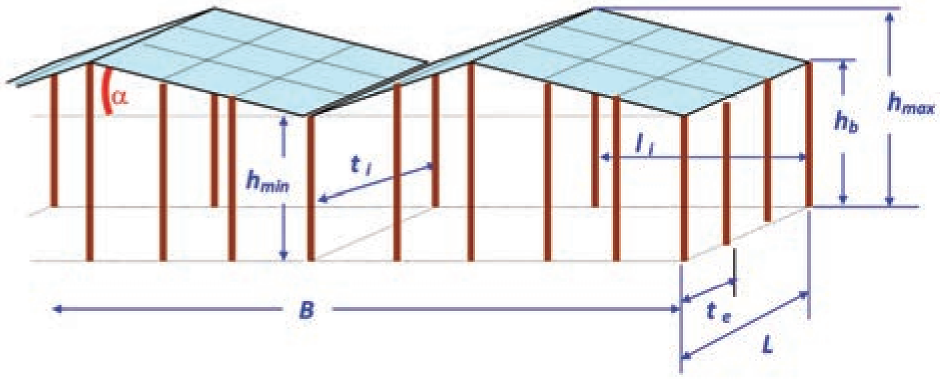
Greenhouse/Regions	B (m)	L (m)	S_c (m²)	V (m³)	l_i (m)	t_i (m)	t_e (m²)	h_{max} (m)	h_{min} (m)	h_b (m²)	α (º)
Flat	77,8	115,8	9.452,7	29.537,0	1,3	1,7	1,8	3,2	3,1	2,9	3,7
‘Raspa y amagado’	76,1	137,3	10.443,1	42.025,0	2,0	7,3	2,1	4,4	3,5	2,9	13,0
Asymmetric	75,7	146,1	10.758,6	42.932,0	2,0	9,8	2,2	4,6	3,4	2,8	8,6/24,1
Multi-span cylindrical	83,8	150,6	12.400,0	67.249,0	6,1	7,7	2,4	6,1	4,4	4,6	
Multi-span gothic	93,3	167,0	15.166,7	89.283,0	5,0	8,5	3,5	6,9	4,7	4,7	
Campo de Dalías	81,7	134,8	11.303,7	43.896,6	1,9	6,6	2,2	4,1	3,4	2,9	
Campo de Níjar	75,3	135,4	9.795,1	44.533,2	2,1	6,4	2,1	5,0	3,8	3,4	
Bajo Andarax	64,4	146,4	8.826,6	36.430,0	1,9	7,2	2,1	4,5	3,6	3,1	
Bajo Almanzora	54,8	130,4	7.288,9	26.769,4	2,2	9,2	2,2	4,5	2,7	2,3	
Province of Almería	**76,9**	**136,3**	**10.503,0**	**42.293,3**	**1,9**	**7,1**	**2,2**	**4,4**	**3,5**	**3,0**	

Survey of 1997

Greenhouse/Regions	B (m)	L (m)	S_c (m²)	V (m³)	l_i (m)	t_i (m)	t_e (m²)	h_{max} (m)	h_{min} (m)	h_b (m²)	α (º)
Flat	51,3	123,0	6 189,3	15 366,7	2,2	3,4	2,0	2,8	2,1	2,0	
‘Raspa y amagado’	54,4	131,2	7 037,6	20 728,5	2,1	4,1	2,1	3,3	2,4	2,2	7,2
Asymmetric	59,1	119,2	7 150,0	22 994,4	2,1	4,1	2,0	3,6	2,5	2,3	7,6/14,0
Multi-span cylindrical	54,3	134,0	7 276,0	27 489,9	3,6	6,1	3,6	4,0	2,9	2,9	
Gabled	52,1	113,5	5 892,3	14 893,5	2,4	4,0	2,0	3,1	2,1	2,1	4,7
Campo de Dalías	53,7	125,0	6 755,5	17 403,8	2,2	3,6	2,0	2,9	2,1	2,1	
Campo de Níjar	48,9	131,8	5 824,6	16 937,8	2,0	3,7	2,0	2,9	2,4	2,1	
Bajo Andarax	52,2	109,2	5 848,4	16 316,0	2,1	3,7	1,9	3,0	2,4	2,2	
Bajo Almanzora	48,3	106,5	4 793,5	15 348,8	2,8	4,5	2,5	3,9	2,5	2,3	
Province of Almería	**52,5**	**124,9**	**6 456,9**	**17 186,7**	**2,2**	**3,7**	**2,0**	**2,9**	**2,2**	**2,1**	

* B width, L length of the greenhouse, S_c surface of covered ground, V volume of the greenhouse, l_i separación transversal entre apoyos interiores, t_i separación longitudinal entre apoyos interiores, t_e separación longitudinal en los apoyos exteriores, h_{max} altura bajo cumbrera, h_{min} altura bajo canal, h_b altura en las bandas, α pendiente de la cumbrera (véase la Figura 147).

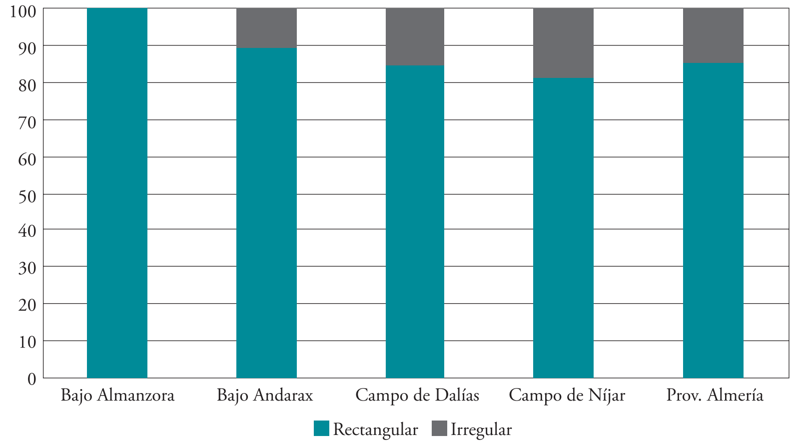
Figure 211. Geometric characteristics of the greenhouses



In addition to increasing the surface and height, an increase in the ridge slope has also been observed from 7.2° in 1997 to 13.0° today (Table 25), which is beneficial because increases in the roof slope are known to improve the uptake of solar radiation during the winter months.

Most of the greenhouses are of rectangular shape today, although in 15 % of the farms, the structure must adapt to the shape of the plot (Figure 212), which in some cases may compromise the structural safety of the greenhouse.

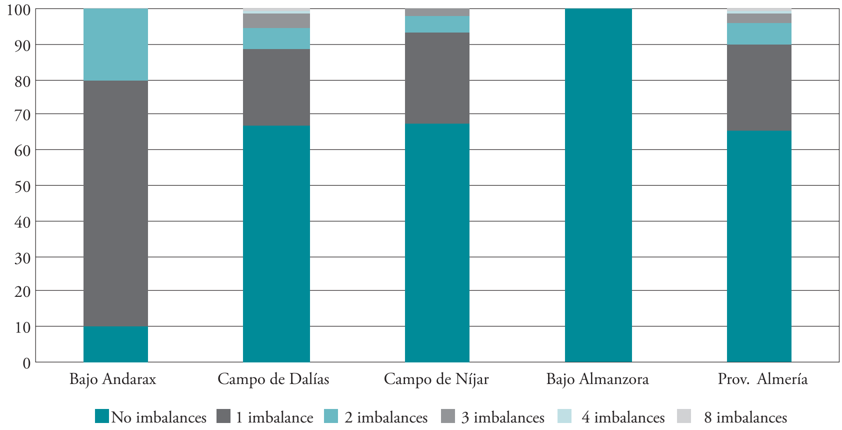
Figure 212. Geometry of the greenhouses. In percentage



The Almería-type greenhouses adapt better to plots that have irregular shapes (imbalanced) because the construction of this structure is made in situ through the development of a network of steel cables that form the horizontal structure of the greenhouse. For multi-span greenhouses with a prefabricated steel structure, their assembly in the field should have almost millimetric precision, and any imbalance in the parts must be verified to determine the exact measurements of the differences. The construction of arches, braces and diagonals with different measurements of imbalances greatly increases the manufacturing costs of greenhouses.

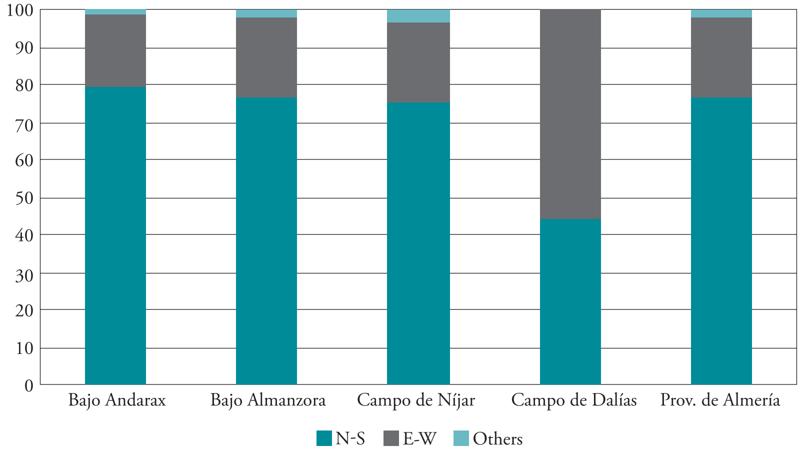
The greenhouses of the surveyed farmers have imbalances in 40 % of the cases (Figure 213), which is a consequence of the poor land planning in Almería that has resulted in plots with very irregular shapes.

Figure 213. Number of imbalances in a rectangular plot. In percentage



Greenhouses are also characterised by their orientation, N-S in 77 % of the cases (Figure 212), which might be caused by the design prioritisation by farmers of longitudinal windows placed at right angles to the eastern and western prevailing winds in Almería. In asymmetric greenhouses (Table 25), the orientation is exactly opposite (78.6 % are oriented in the E-W direction), which maximises solar radiation uptake so that the plants can increase their photosynthetic activity.

Figure 214. Orientation of the ridge of the greenhouses. In percentage



Construction materials of the greenhouses

Greenhouses built today have mostly metal supports, which are composed of galvanised iron pipes or rolled profiles (Table 27). In addition, many farmers have replaced damaged wooden supports in their old greenhouses with new metallic supports.

Table 27. Construction material of greenhouse supports

	Types of interior supports					Types of perimeter supports				
Material	**Wood**	**Pipe**	**Beam**	**Profile**	**Others**	**Wood**	**Pipe**	**Beam**	**Profile**	**Others**
2013										
Flat	4,2	70,8	16,7	4,2	4,1	16,7	25,0	50,0	8,3	
'Raspa'	12,3	79,6	4,9	0,6	2,6	8,0	38,9	50,6	1,9	0,6
Asymmetric		85,7		7,1	7,2		35,7	57,1	7,1	0,1
Multi-span		87,5	12,5				75,0	25,0		
Gothic		100,0					33,3	66,7		
Almería	**11,0**	**79,0**	**5,9**	**1,4**	**2,7**	**8,3**	**35,5**	**52,1**	**3,7**	**0,5**
1997										
Material	**Wood**	**Pipe**	**Beam**	**Profile**	**Concrete**	**Wood**	**Pipe**	**Beam**	**Profile**	**Concrete**
Flat	63,5	30,2	5,4		0,9	53,0	26,3	20,1		0,6
'Raspa'	44,1	50,7	3,7		1,5	36,6	40,3	23,1		
Asymmetric	43,7	43,7	12,6			25,0	31,2	43,8		
Gabled	47,0	35,3	17,7			29,4	35,3	35,3		
Multi-span		100,0				0,0	100,0	0,0		
Almería	**56,4**	**37,0**	**5,6**		**1,0**	**46,4**	**31,3**	**21,9**		**0,4**

Evolution of natural ventilation systems

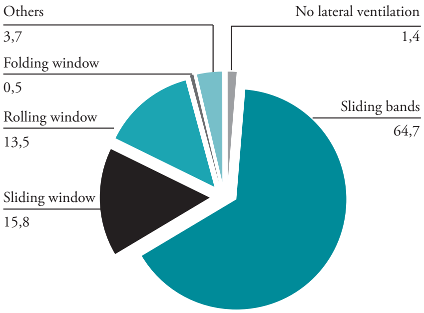
The greenhouses in Almería have optimised their ventilation systems over the past 16 years by improving the operation systems of the lateral side windows (Figure 215).

Thus, 64.6 % of greenhouses currently have bands for sliding down the plastic films between the double vertical wire mesh (Figure 216). Although this system is still the most common, its use has decreased since 1997, when it was used by 87.7 % of farmers. Today, more elaborate systems are being installed, such as roll-up windows (13.5 %) or sliding windows with a mechanical operation system (15.8 %).

The analysis of roof ventilation systems indicates a large increase in the percentage of greenhouses with such systems, with the value increasing from 68.9 % in 1997 to 95.4 % in 2013 (Figure 216). In addition, large diversification is observed in the types of windows used, with a majority of flip windows installed (65.1 %).

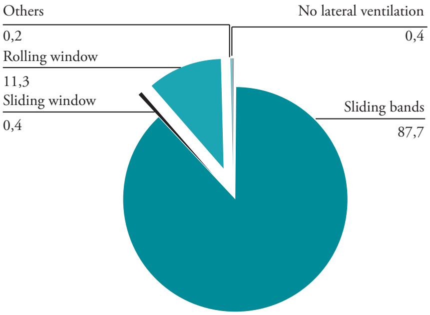
Figure 215. Evolution of the types of side openings over the past 16 years. In percentage

2013



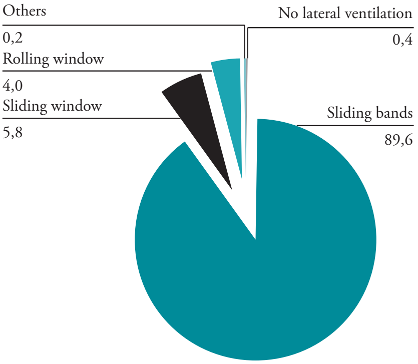
Source: Survey. Own elaboration.

1997



Source: Molina-Aiz (1997).

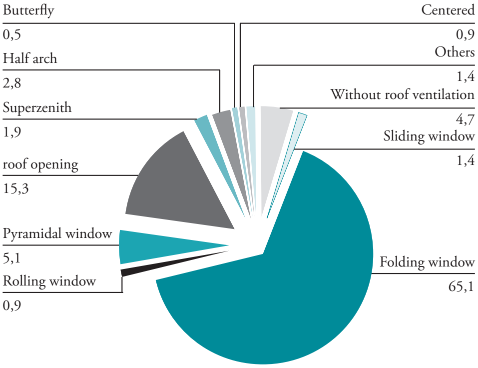
2004



Source: Fernández y Pérez-Parra (2004).

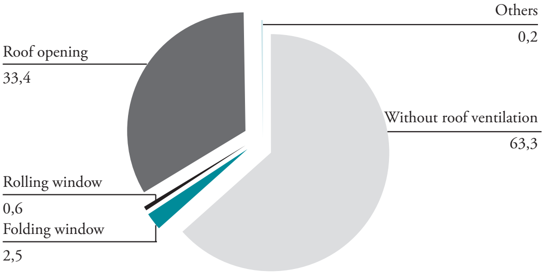
Figure 216. Evolution of the types of roof openings over the past 16 years. In percentage

2013



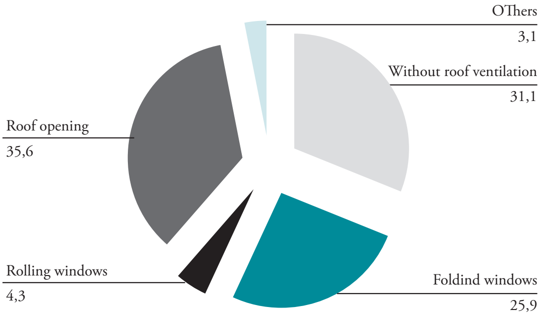
Source: Survey. Own elaboration.

1997



Source: Molina-Aiz (1997).

2004



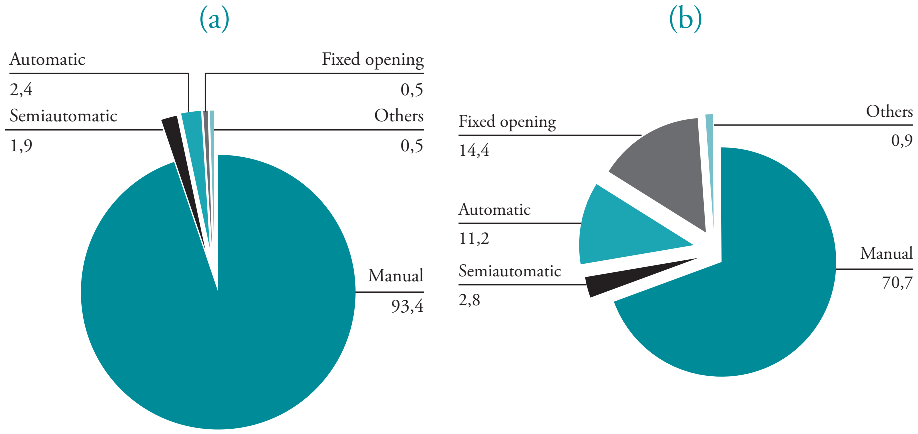
Source: Fernández y Pérez-Parra (2004).

Similarly, a reduction in the percentage of greenhouses with fixed roof ventilation openings has been observed (from 33.4 % in 1997 to 15.4 % today), whereas no increase has been observed for the difficult roll-up type of automation, and new designs, such as pyramidal-type windows, have been installed (Figure 216).

With respect to multi-span greenhouses, various types of windows have been produced, although the most common is still the half arch, which was the first window installed in these types of greenhouses.

The majority of farmers open and close the lateral windows manually (Figure 217a), and only 2.4 % manage them automatically, which corresponds in almost all cases with multi-span greenhouses. Installations of windows (Figure 217b) with automated openings (11.2 %) or semi-automated openings with geared motors that the farmer can start with a manual switch (2.8 %) have increased.

Figure 217. Operation systems for side (a) and roof openings (b)



Ventilation surface

The available ventilation surface in greenhouses is a parameter that directly influences the climate inside the greenhouse. In the Almería type, the available ventilation surface, along with local wind speeds, directly determines the thermal gradient between the inside and outside of the greenhouse (Molina-Aiz, 2010).

The analysis of the evolution of the ventilation surface shows a clear increase in the average surface of total ventilation (Av/Sc) for Almería-type greenhouses (Table 27), whereas a decrease can be observed for multi-span greenhouses. The surface increase of flat and raspa y amagado greenhouses is based on a slight increase in the average installed surface as well as on a large increase in the percentage of greenhouses that have roof ventilation (Table 28).

In the case of the multi-span greenhouses, a reduction in the total area of ventilation (A_v/S_c) has been observed. This decrease is related to the reduction of lateral ventilation surface (A_{vl}) caused by a lack of lateral window installations in the front of the greenhouse, and it is also related to the large increase of covered ground surface (S_c) by this type of greenhouse (which has increased from an average area of 7,276 m^2 in 1997 to 12.400 m^2, Table 26).

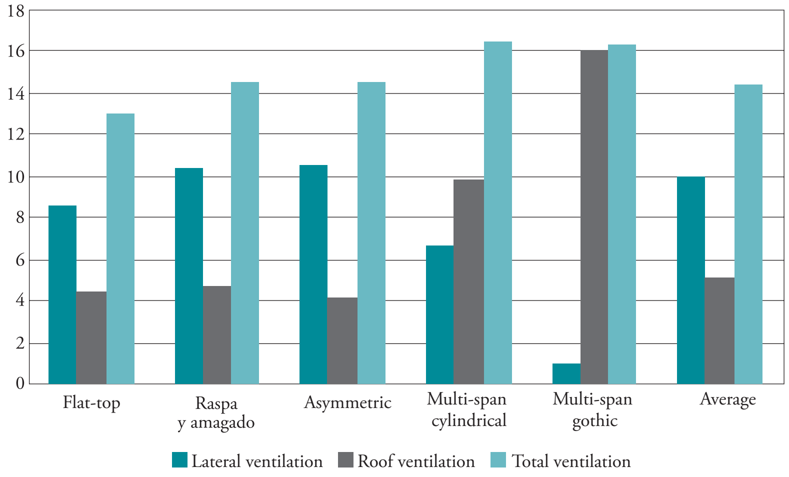
Table 28. Average percentages of side ventilation surface (A_{vl}/S_c)and roof ventilation (A_{vc}/S_c) in greenhouses that contain them (VC) and average percentage of total ventilation surface (A_v/S_c) for the set of all greenhouses

Greenhouse/Regions	A_{vl}/S_c	A_{vc}/S_c	*VC*	A_v/S_c	A_{vl}/S_c	A_{vc}/S_c	*VC*	A_v/S_c
Survey	**2013**				**1997**			
Flat	8,6	4,5	95,8	13,0	9,1	3,4	31,5	8,8
‘Raspa y amagado’	10,4	4,7	88,9	14,5	9,2	4,4	40,7	9,1
Asymmetric	10,5	4,1	85,7	14,5	9,6	8,4	46,7	10,2
Multi-span cylindrical	6,6	9,9	100,0	16,5	12,2	8,1	100,0	20,3
Multi-span gothic/gabled*	1,0	16,0	100,0	16,4	8,7*	3,0*	57,8*	8,3*
Campo de Dalías	8,5	4,9	88,6	9,0	9,3	4,0	40,4	8,3
Campo de Níjar	10,3	6,1	81,4	15,0	10,1	3,3	18,3	8,6
Bajo Andarax	14,5	4,5	89,3	18,6	9,4	3,3	46,1	8,6
Bajo Almanzora	10,1	4,3	100,0	14,3	11,3	5,0	50,0	11,2
Province of Almería	**10,0**	**5,1**	**95,4**	**14,4**	**9,1**	**3,8**	**36,3**	**8,9**

The side ventilation surface (A_{vl}/S_c) of gothic-type greenhouses has decreased dramatically along with increases in the covered ground surface, which is related to the lack of lateral windows in these structures caused by farmers who believe that insect pests can enter through these windows more easily than by roof windows located at higher altitudes. The lack of lateral ventilation presents a serious problem in conditions of weak wind and high temperatures, which promote a reduction of air flow because of the buoyancy of hot air.

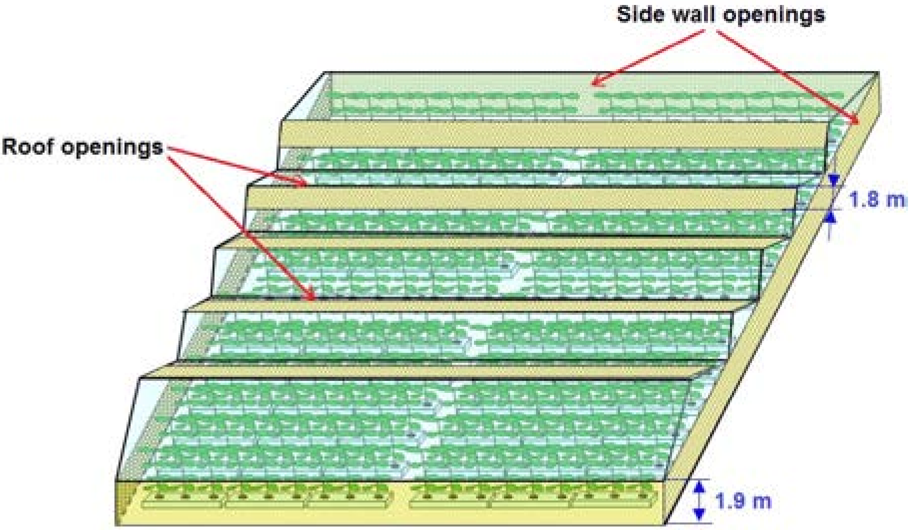
The poor ventilation capacity of these greenhouses must be improved because they have an average value of 14.4 % (Figure 218), which is far from the minimum value of 30 % of the covered surfaces required for correct ventilation (Molina-Aiz, 2010) or even the value of 25 % recommended by the Integrated Production Regulation.

Figure 218. Percentages of side, roof, and total ventilation surfaces of different types of greenhouses and average values for all structures. In percentage



To increase the surfaces in Almería-type raspa y amagado greenhouses, roof openings should be installed in the ridges of all modules and the surface of lateral openings should be increased as much as possible along the four bands of the greenhouse (Figure 219). To obtain an adequate rate of air renewal in greenhouses (R = 45 h^{-1}) and limit the thermal gradient to 5 ºC, the ventilation surface must be increased to 35 % of the covered surface to compensate for decreases in flow caused by insect screens and crops (Molina-Aiz, 2010).

Figure 219. Diagram of the Almería-type greenhouse with the necessary windows to achieve a ventilation surface that is 35 % of the covered surface



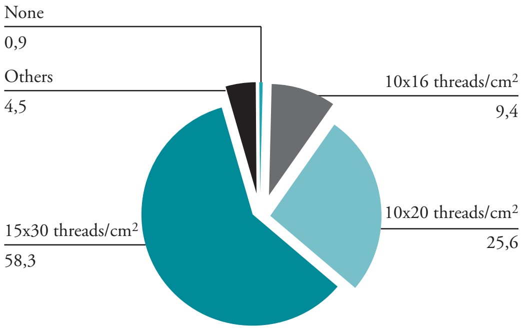
Source: Molina-Aiz (2010).

Passive systems of pest protection

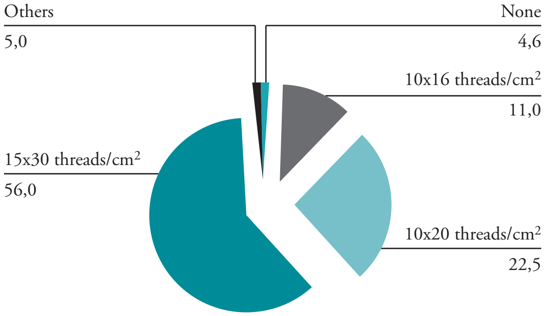
The vast majority of greenhouses in Almería have some type of insect-proof screens as a passive protection system against the entry of insect pests (Figure 220). The most commonly used for roof windows is the 15 × 30 hilos/cm^2 screen (Figure 220b), and such protection has been mandated by the Andalusian legislation for establishing mandatory control measures in the fight against viral diseases in horticultural crops (ORDER of 12 December 2001, BOJA No. 3 Sevilla, 8 January 2002). The use of this type of protection is also mandated by the Specific Regulations of the Integrated Production of Protected Horticultural Crops, as previously mentioned.

Figure 220. Density of insect screens used in the lateral windows (a) and roof windows (b) of the Almería greenhouses surveyed. In percentage

(a)



(b)



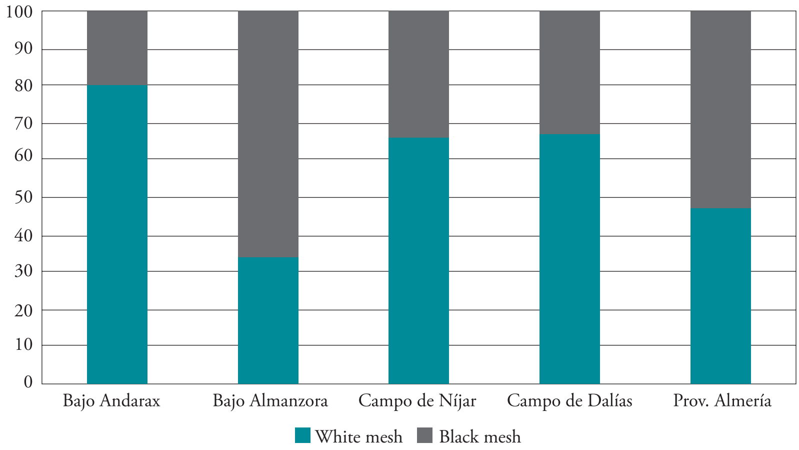
Lateral windows, which are subjected to greater pressure from thrips, commonly use screens that are denser (15 × 30 hilos/cm^2) than what is required by the above-mentioned standards (Figure 220).

Screens with 10 × 16 hilos/cm^2 are used in 9.4 % of lateral windows and 11.09 % of roof windows (Figure 220). Although these nets are less dense than those indicated by the Andalusian regulations, they are authorised for use in the case of poor greenhouse ventilation.

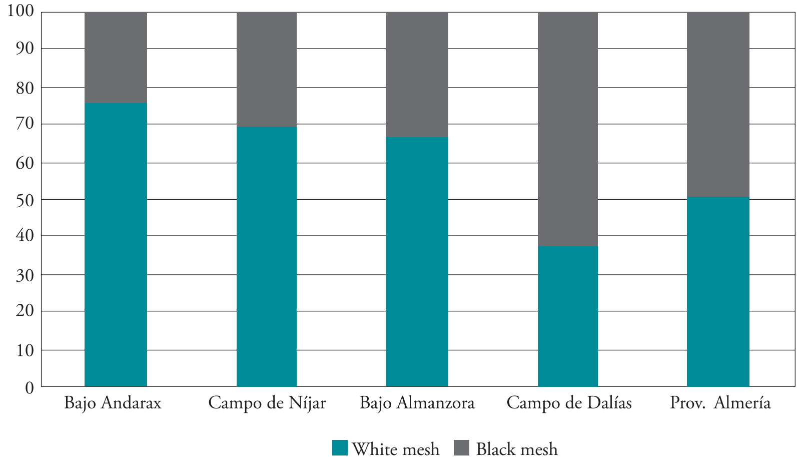
The type of material used for screen manufacture is equally divided between high density polyethylene mesh (PEhd) with black threads and with semi-transparent or white threads (Figure 221), with the latter used much less frequently in the roof windows of structures in Campo de Dalías (36 %) and the lateral windows of structures in Bajo Almanzora relative to the other three regions (66-80 %). The transparency to solar radiation of white screens is approximately 75 %, whereas the black screens usually have lower transmissivities of 30 %.

Figure 221. Colour of insect-proof screens in the side (a) and roof openings (b)

a) Lateral windows

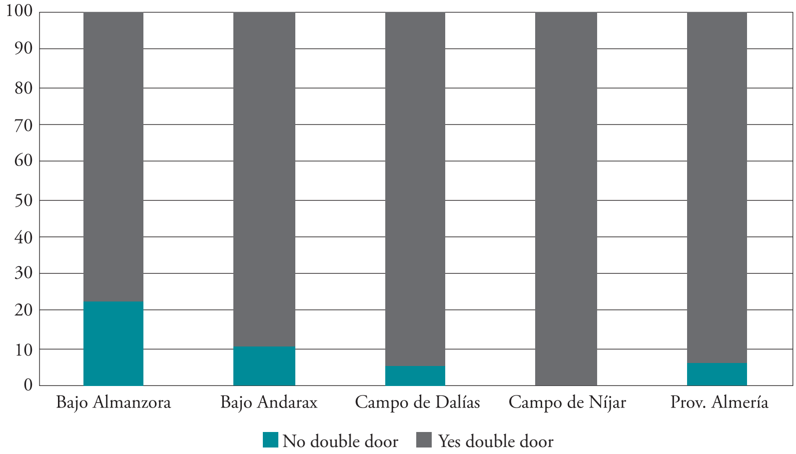


b) Roof windows



Another mandatory passive protection measure in the Andalusian regulations for protection against viral diseases is double doors in the greenhouse. Thus, 94 % of the Almería greenhouses have a double door, with the lowest use found in the Bajo Almanzora region at 78 % (Figure 222).

Figure 222. Percentage of greenhouses with double doors



Greenhouse cover materials

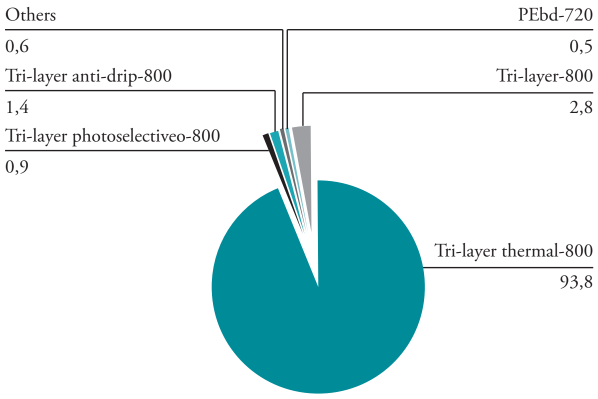
The analysis of the evolution of cover materials shows that from 1997 to 2013, an important change in cover material occurred (Figure 223). Low density polyethylene sheets (PEld) with 720 gauge thickness covered 55 % of the greenhouses surveyed in 1997. However, the majority of farms (93.8 % of the greenhouses sampled) currently use the three-layer coextrusion film of polyethylene/ethylene vinyl acetate/polyethylene (PE-EVA-PE) with 800 gauge thickness and additives to improve its thermal effect.

In 1997, the distribution of different cover materials was more heterogeneous, and 800 gauge PEld, which was the fourth-most common, represented 8.6 % of the greenhouses. However, 800 gauge three-layer plastic is now the second-most common type, and it is only installed in 2.8 % of the greenhouses.

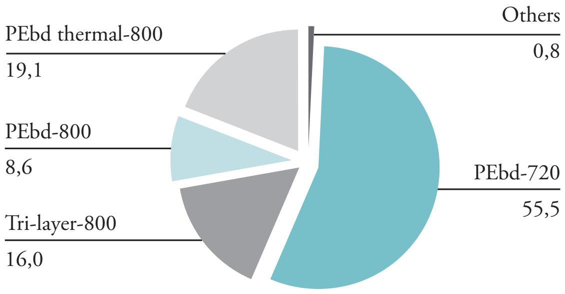
In addition to the three-layer plastic with thermal properties, three-layer non-drip and photo-selective type coverings are used to a much lesser extent, with percentages of 1.4 and 0.9 %, respectively.

Figure 223. Evolution of cover materials over the past 16 years: surveys of 2013 (a) and 1997 (b). In percentage

2013 (a)



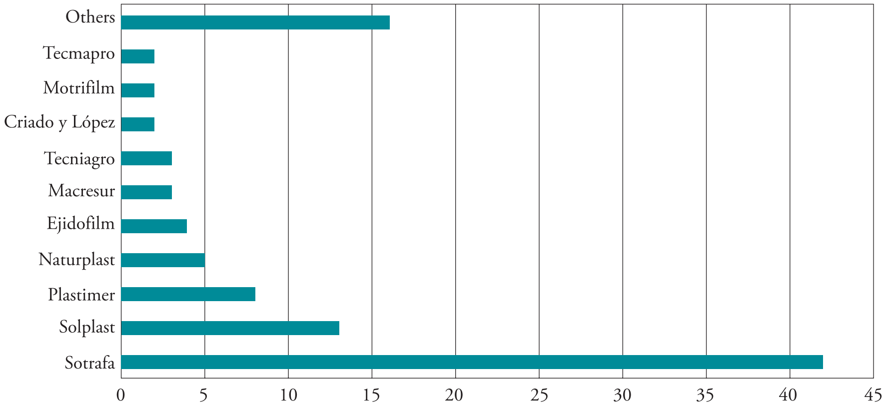
1997 (b)



As for the colour of the plastic, a high degree of homogeneity is observed, with 96.2 % of the farmers using white transparent plastic (100 % in Bajo Andarax, Campo de Dalías and Campo de Níjar), 2.8 % using yellow plastic and 0.5 % using green plastic, although yellow and green are only used in the Bajo Andarax region (Figure 224).

The origin of plastic in the greenhouse is varied, although the top manufacturer holds 42 % of the market, the second holds 13 %, and the remainder hold 2-8 % (Figure 225).

Figure 225. Origin of the plastic used by the surveyed farmers. In percentage



The durability of the plastic covering has been reported as three years by 92 % of the surveyed farmers (Figure 226), although it can last up to four to five years, with especially long durability in Campo de Níjar.

The cost of the cover material shows clear variations depending on the region in which the greenhouse is located. The price of plastic films is most expensive in the Bajo Andarax region, followed by the Campo de Dalías and Campo de Níjar regions, with the lowest cost in Bajo Almanzora. Furthermore, this variation is observed for the price indicated in €/m^2 for certain farmers and €/kg for different farmers (Figure 227).

Specialised crews are hired by 95 % of the farmers to change the plastic in the greenhouses (100 % in Bajo Andarax and Bajo Almanzora), whereas only 2.3 % of the farmers install it with the help of neighbouring farmers (Figure 228).

Figure 226. Average durability of plastic

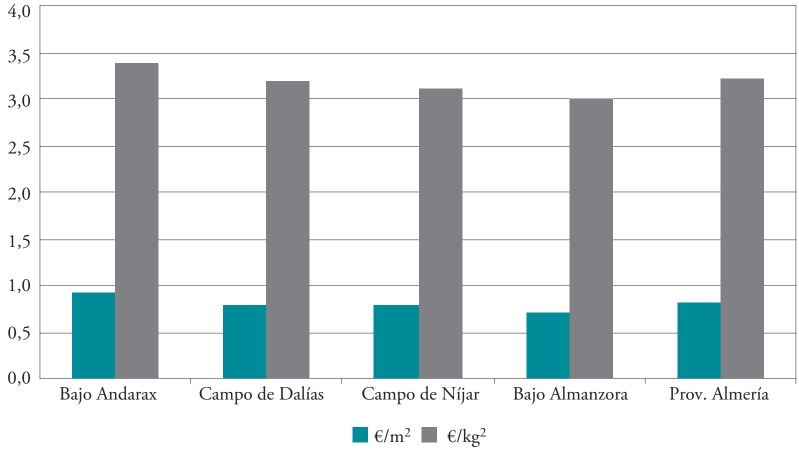


Figure 227. Average cost of plastic cover

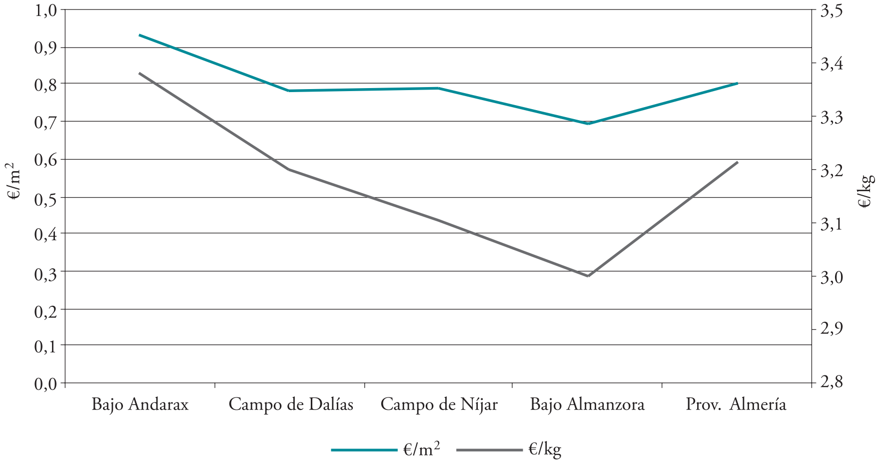
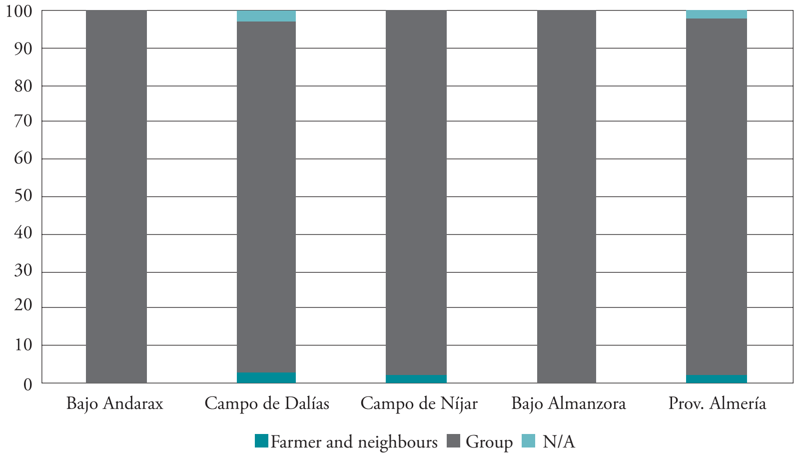


Figure 228. Changing of the plastic cover in the greenhouses. In percentage

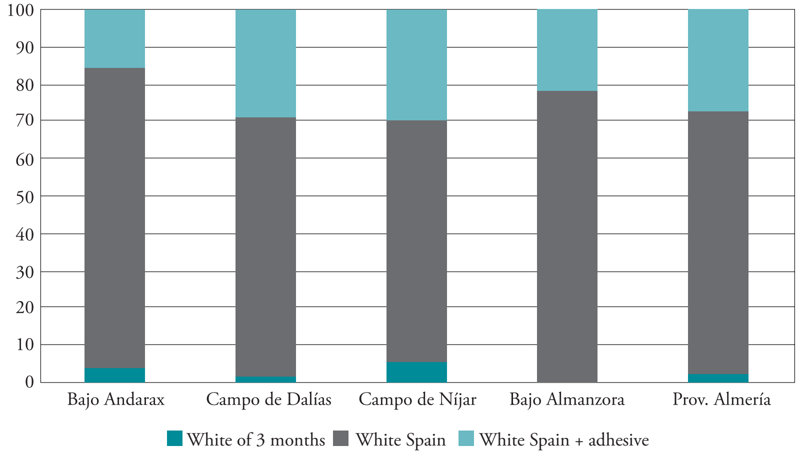


Whitening of the greenhouse covers

The vast majority of farmers in Almería (99 %) whitewash the greenhouse cover to increase its reflection coefficient to solar radiation, which reduces the contribution of energy that heats the greenhouse during the central hours of the day.

The majority of surveyed farmers use micronised calcium carbonate (Blanco de España, or White of Spain) to whitewash the greenhouse covering (88.1 %), whereas a quarter also add adhesive (Figure 230) to improve its permanence on the greenhouse covering, and only a limited number of farmers add lime after three months (2.4 %). Large variations have not been observed between the different producing regions in terms of whitewashing with adhesive.

Figure 230. Products used for whitening the greenhouse cover. In percentage



Application of the product is performed with spraying systems that include spears and nozzles to direct the flow, which results in a distribution that is never completely uniform. The intensity of the shade (transmissivity of the covering) can be adjusted by altering the dosage of calcium carbonate in water. The dosage varies greatly by region (Figure 231), with higher values observed in Campo de Dalías (0.43-0.46 kg L^{-1}) and Campo de Níjar (0.34-0.37 kg L^{-1}). The farmers in these two regions reduce the whitewashing dose according to the increasing age of the plastic, which loses transmissivity with time. Bajo Almanzora and Bajo Andarax use much smaller concentrations of calcium carbonate, and less variation is observed according to the age of the plastic film.

Farmers whitewash (Figure 232) at the beginning of the autumn-winter (August) and spring-summer (February, March and April) crop cycles.

Most of the farmers clean the greenhouse cover (Figure 233) when the solar radiation is insufficient (mainly at the end of autumn or beginning of winter) by using pressurised water (38.5 %) or brushes with water (29.8 %). In addition, the use of cleaning machines that automatically brush the plastic is becoming more widespread (11.1 %). In some cases, the farmers simply let the rain naturally wash the calcium carbonate (17.9 %).

Figure 231. Dose used in whitening in the different regions and according to the age of the plastic film. In kg L^{-1}

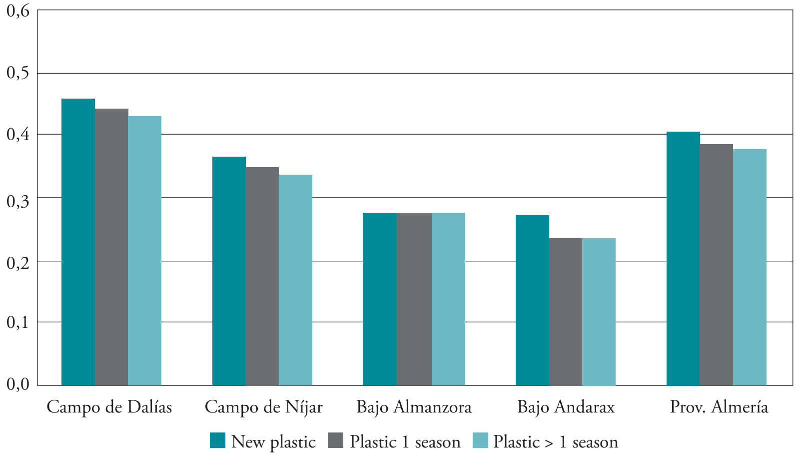


Figure 232. Percentage of farmers that whitewash in the different months of the growing season. In percentage

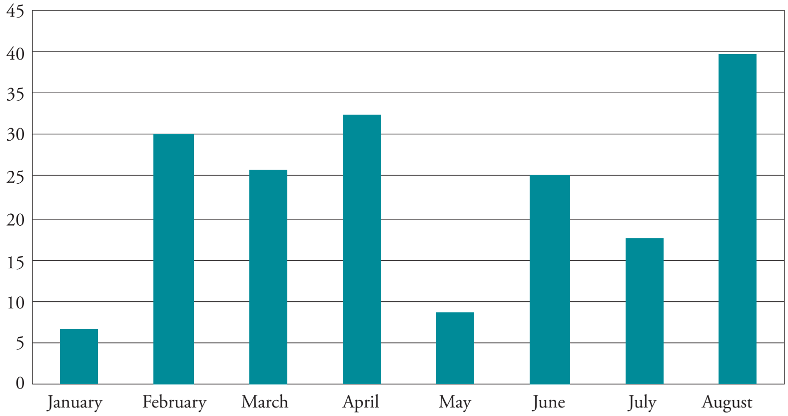
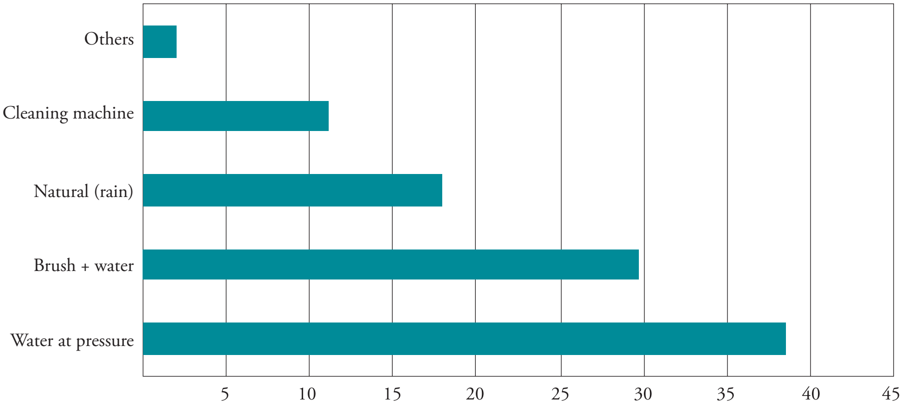


Figure 233. Cleaning systems used for the covering



4.8. Climate control systems

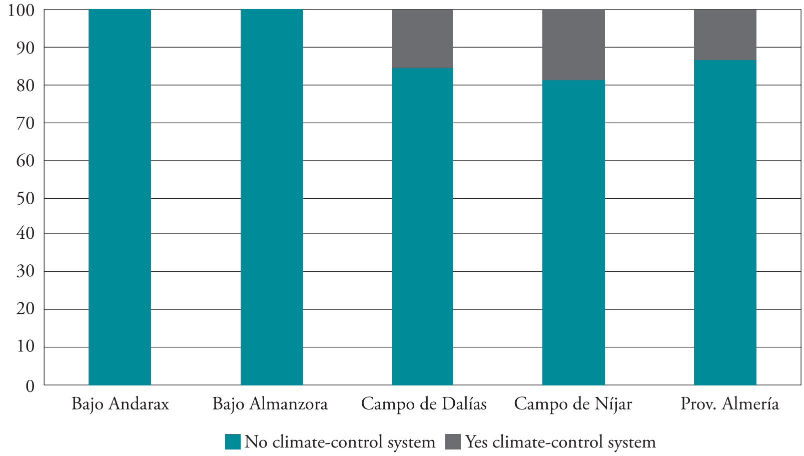
One of the aspects that can improve the productivity of agricultural crops is the use of active climate control systems. However, the high energy costs associated with a number of these systems, such as heating systems, along with the stagnation of selling prices of fruits and vegetables, increase the difficulty of their widespread incorporation in this sector.

Automated climate management systems

The use of climate management systems with microprocessors and computers (Figure 234) is closely linked to the level of climate control technology installed in the greenhouse. Similarly, the installation of thermal screens or heating systems is directly related to the type of greenhouse structure. Thus, the cylindrical or gothic multi-span type greenhouses tend to have more equipment that must be managed by a climate controller. As such, 94 % of the multi-span greenhouses sampled have this equipment, whereas only 14.3 % of the asymmetric and 9.9 % of the raspa y amagado have it installed. As expected, none of the farmers with flat-type greenhouses have this technology.

The distribution of climate controllers by regions indicates that 19 % of the greenhouses of Campo de Níjar and 15 % of those of Campo de Dalías have climate controllers, whereas these systems are not observed in any of the greenhouses analysed in the Bajo Andarax and Bajo Almanzora regions (Figure 234).

Figure 234. Percentages of greenhouses equipped with climate controllers. In percentage



Mobile energy conservation systems

The use of thermal screens to reduce radiative energy loss overnight is restricted to only 2.4 % of the greenhouses sampled, with 25 % found in the multi-span type with direct-combustion air heating and climate controllers and the remaining 75 % in raspa y amagado greenhouses without heating or climate control by microprocessors.

Similarly, only 1.9 % of the surveyed farmers use shade screens to control incident solar radiation throughout the day. It is worth noting that these numbers correspond to raspa y amagado greenhouses without heating or climate control (75 %) and gothic greenhouses with air conditioning (25 %).

Forced ventilation systems

The vast majority of greenhouses in Almería do not use forced ventilation systems because these systems involve a large investment and high consumption of electric power, which increase production costs. Thus, only 4.2 % of the surveyed greenhouses are equipped with exhaust fans to carry out forced ventilation and to increase the number of air exchanges when wind speed is low and natural ventilation is insufficient. Similarly, a limited number (3.3 %) of greenhouses have fans inside the greenhouse (destratifiers) to move and recirculate interior air to obtain more homogeneous microclimatic conditions inside the greenhouse.

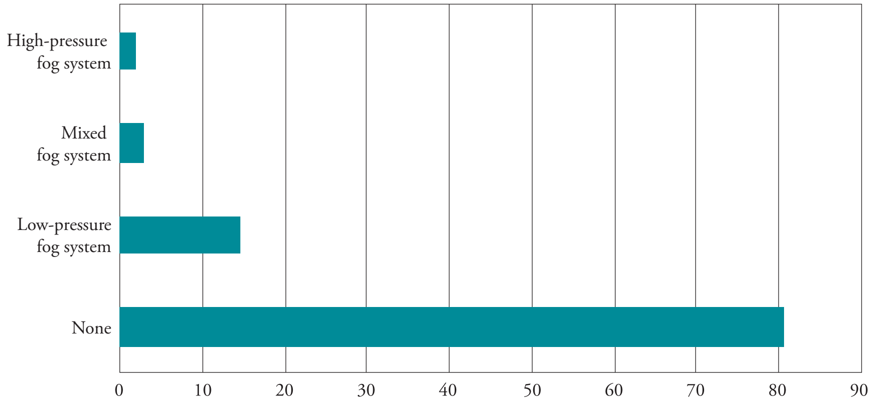
It is remarkable that only 9 % of the multi-span greenhouses (including cylindrical and gothic) use destratification fans and none use exhaust fans. It is also striking that 4.3 % of the flat-top greenhouses use exhaust fans, which may be an attempt to alleviate the inefficiency of their natural ventilation system. This percentage is similar to that of raspa y amagado greenhouses with exhaust fans (3.7 %), which are concentrated in Bajo Andarax. In this region, 11 % of the total greenhouses install exhaust fans. An equivalent percentage of the raspa y amagado greenhouses (3.1 %) install small destratification fans, especially in Campo de Níjar, where 7 % of the total greenhouses sampled have this equipment.

Evaporative water cooling systems

The most extensively used active climate control in greenhouses in Almería is cooling by evaporation of water through fixed networks of fog systems, which are installed in 19.3 % of the greenhouses and primarily consist of low-pressure water systems (Figure 237). The incorporation of this system in the greenhouses of Campo de Dalías is high at 23 %, which is in contrast to the 2 % incorporated in Campo de Níjar or 0 % incorporated in the Bajo Andarax and Bajo Almanzora regions.

The use of fog systems does not appear to be exclusively related to the type of structure because this technique varies between 16.7 % for flat-top greenhouses to 22.0 % for semi-cylindrical covered multi-span greenhouses. Its use in gothic-type greenhouses is 66.7 %, which is most likely because this technique does not require sealing of the greenhouse to avoid saturation by water vapour from the mixture of moist air; thus, it can continue cooling the greenhouse environment.

Figure 237. Cooling systems by water evaporation in greenhouses in Almería. In percentage



Heating systems

Similar to ventilation or evaporative cooling systems, the introduction of heating systems is still limited in the greenhouses of Almería at only 8.4 % (Figure 238). The most widely used system is heating by indirect combustion (3.3 %) using heaters equipped with a heat exchanger and chimney for evacuation of gas outside the greenhouse. The second-most common system are known as cannons or direct-combustion heaters (2.8 %), which discharge fumes from combustion inside the greenhouse, although they have a high thermal performance of 100 %.

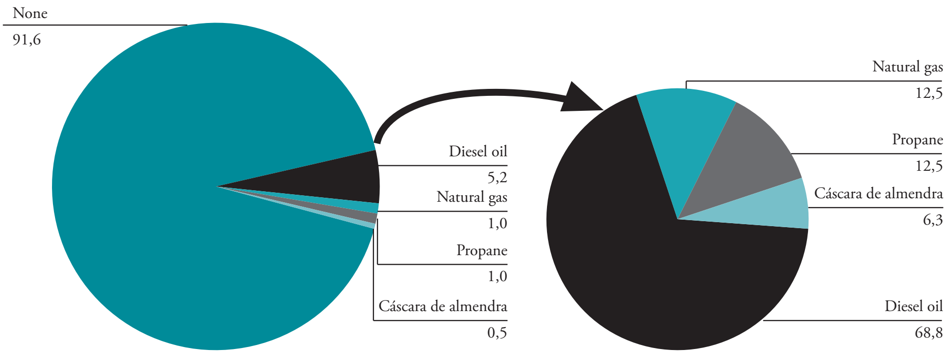
Heating systems using hot water pipes are only observed in 0.5 % of the greenhouses surveyed, indicating its low acceptance in this sector, although this may be caused by the prohibitively high investment required for its installation. Such an investment is only justifiable for continued use during a large part of the crop period, and such use is not necessary in the province of Almería because of its warm climate.

The installation of heating systems is closely linked to the type of structure because 66.7 % of the multi-span greenhouses are equipped with heating systems, whereas only 4.9 % of raspa y amagado greenhouses are equipped with these systems. In addition, 50 % of the greenhouses with heating systems are equipped with climate controllers for their automated management.

As for fuels used for heating systems, the most common is diesel fuel, which accounts for 68.8 % of the heated greenhouses (Figure 239), followed by natural gas and propane gas, each accounting for 12.5 % of heating installations.

Almond shell is used as a fuel in heating systems that use air through a forced-air furnace with circulation pipes driven by extractors. Almería is a province with a high production of almond shells and olive stones, which are two biofuels that may be used in the future as alternative fuels for emergency air heaters used for sudden decreases in temperature that can damage crops, which tends to occur every decade in Almería.

Figure 239. Fuels used for the heating systems in in the totality of greenhouses and with respect to those with heating systems. In percentage



Energy-saving techniques

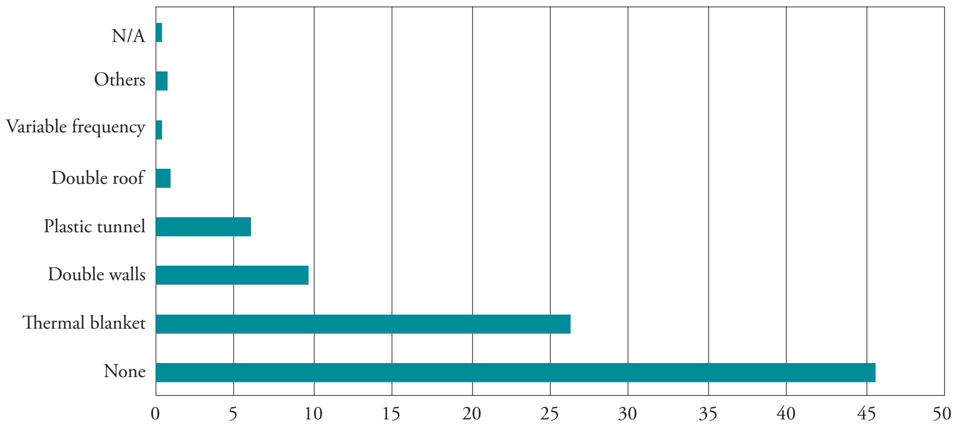
Unlike heating systems, energy-saving systems appear to be widespread among the greenhouses of Almería, with 43.9 % of the respondents employing methods of reducing energy losses, especially in winter (Figure 240).

The most widely used system is that of thermal blankets that extend over the crop directly or on a trellis, with this system used by 26.2 % of the farmers, especially in the Bajo Almanzora region, where it is used by 65 % of the farmers because of the greater risk of frost.

Similarly, semi-forced tunnels (micro-tunnels) of PE sheets are primarily used in Bajo Almanzora (18 % of greenhouses), accounting for 6.0 % of the total throughout the province.

The second-most common energy-saving system is that of double walls, which are found in 13 % of the greenhouses in Campo de Dalías, accounting for 9.7 % of the provincial total.

Figure 240. Energy-saving techniques used in greenhouses in Almería. In percentage



Advanced climate control systems

None of the respondents use advanced climate control such as CO_2 injection systems or artificial lighting. Although carbon dioxide enrichment is a technique implemented in Almería, its use is restricted to less than a dozen multi-span or *Venlo* greenhouses.

4.9. Cost-benefit analysis

The profitability analysis of the agricultural holdings indicated once again the importance of specialisation. The most specialised area is the Bajo Andarax region because of tomato specialisation, and it has the highest gross margin of 3.2 €/m^2. The provincial average revenues are 7.01 €/m^2 and costs are 4.12 €/m^2 (Figure 241); therefore, the provincial margin is 2.89 €/m^2. However, the average gross margin per agricultural season in the province is € 39,083.

Each region has a most profitable product, and 96 % of farmers from Bajo Andarax stated that tomatoes provide the greatest profits. The percentages are not as high for the rest of the regions, with the following crops being indicated as the most profitable: pepper (38 %) in Campo de Dalías and tomato (34 %) in Campo de Níjar and (44 %) Bajo Almanzora. Thus, the specialisation of these regions in pepper and tomato crops can be observed.

Of the farmers surveyed, 44 % do not receive subsidies, and this percentage equals that of those who do not rely on external funding (Figure 242). The less indebted region is Bajo Andarax, where 57.1 % do not resort to external funding.

However, more than half of the farmers in the province (56.3 %) require funding (Figure 243). It should be noted that the agricultural sector in Almería has always received important support from Cajamar Caja Rural, which is the first Spanish rural savings bank and credit cooperative, and according to this work, it finances 76 % of the greenhouse operations that require assistance in Almería.

However, half of those surveyed plan to make short-term improvements to their holdings that may require funding.

Figure 241. Income and expenses throughout the season. En €/m²

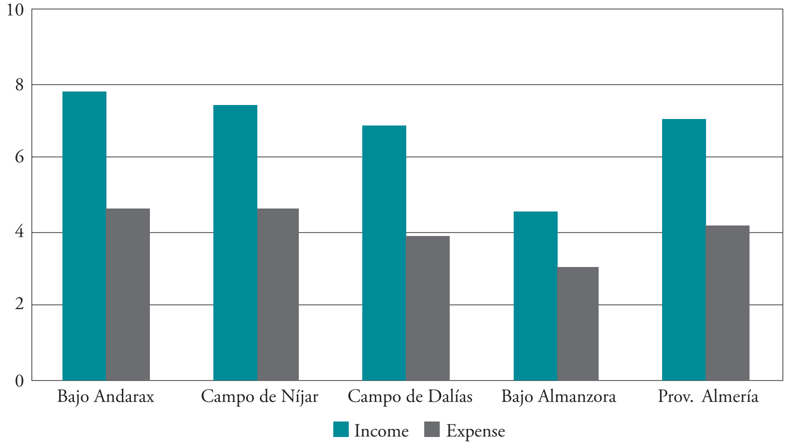


Figure 242. Origin of subsidies obtained by the surveyed farmers. In percentage

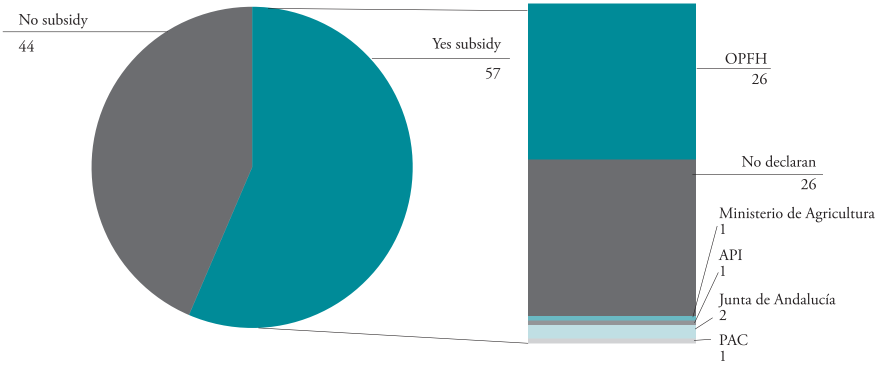
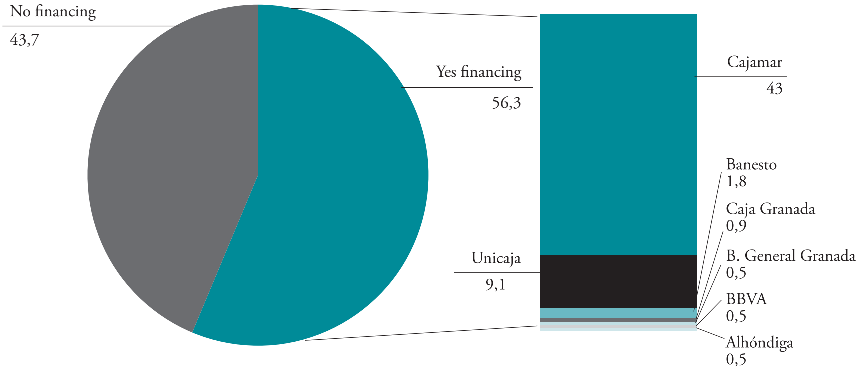


Figure 243. Entities that finance the surveyed farmers. In percentage



4.10. Labour

More than 40 % of the operational costs can be attributed to labour, which is the largest cost, with 64 % of the labour contracted, and 90.4 % of the contracted labour performed by immigrants (Figure 244).

The average workforce is five workers per holding, which primarily employ permanent-intermittent workers (Figure 245).

Figure 244. Labour force employed by the surveyed farmers. In percentage

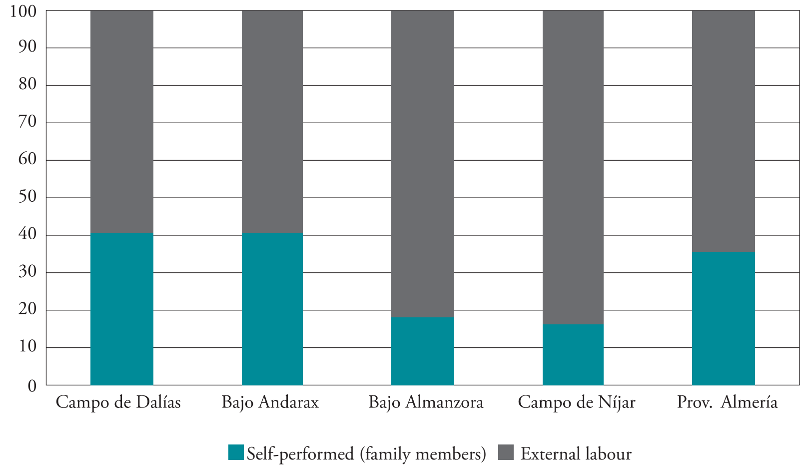
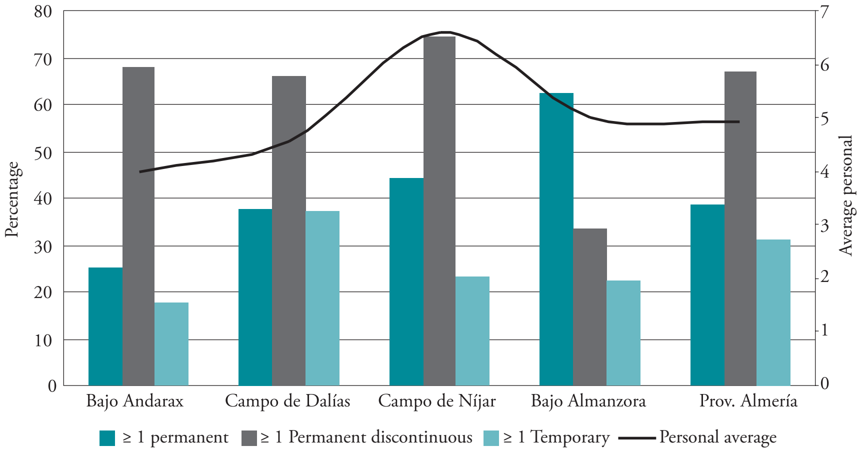


Figure 245. Characteristics of the labour force employed by the surveyed farmers



Farmers generally do not have a preference when hiring labour (69.9 %), although knowing the person is the most important criterion in hiring decisions (Figure 246).

Temporary labour is required in 35 % of the greenhouses during the collection of fruits and vegetables (Figure 247).

Figure 246. Hiring preferences. In percentage

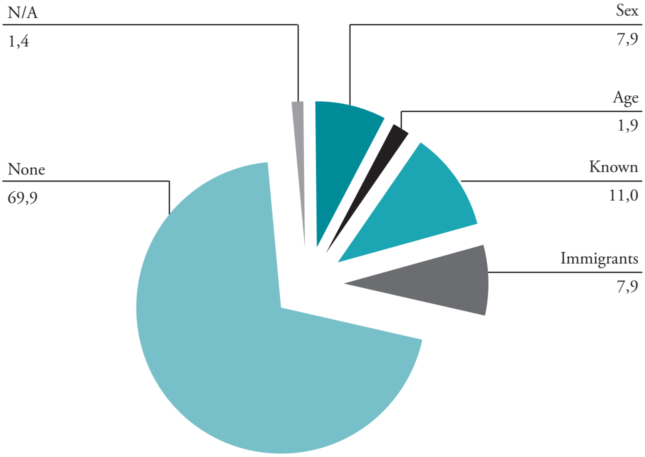
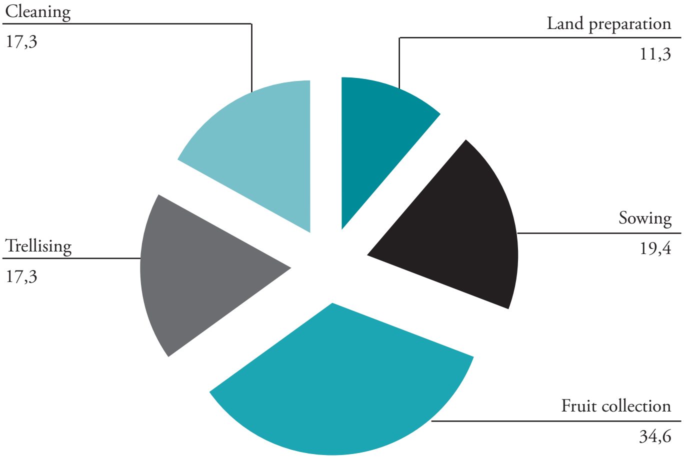


Figure 247. Labour for which temporary personnel is hired. In percentage



5. Most profitable profiles

To obtain the average profiles of the most profitable holdings in each agricultural region, data from the last three seasons (from 2010/11 to 2012/13) were used, and the average of the ten most profitable holdings was calculated. For qualitative questions, the number of responses for each type was specified.

Homogenous patterns were used to avoid the possible distortion that might be produced in the characterisation of the most efficient infrastructures by the market effectiveness of the companies that market the agricultural products, which could be another focus of this study. Thus, we have used the yields (kg m-2) of each particular holding for each crop, cycle and season; but also the average monthly sale prices were considered for each defined harvesting period (depending on the crop type and cycle), which were provided by the Observatory of Prices and Markets of the Regional Government of Andalusia. However, large variations were not observed between the mean gross revenues declared by farmers and those calculated for their holding using the Observatory of Prices and Markets as a homogeneous criterion.

Moreover, an analysis was performed on the profiles of the best ten holdings according to the average production yield for the three seasons analysed. To perform this analysis, each of the crop combinations by season that occurred most frequently in the sample was studied independently:

- Two short cycles of tomato.
- Long-cycle tomato.
- Pepper in autumn-winter and melon in spring-summer.
- Pepper in autumn-winter and watermelon in spring-summer.
- Long-cycle pepper.
- Cucumber in autumn-winter and watermelon in spring-summer.
- Cucumber in autumn-winter and melon in spring-summer.
- Two short cycles of courgette.
- Courgette in autumn-winter and watermelon in spring-summer.
- Courgette in autumn-winter and melon in spring-summer.
- Eggplant in autumn-winter and watermelon in spring-summer.
- Long-cycle of eggplant.

5.1. Average profile of the holding with the highest average estimated revenues by region

The average profile of the farmer who earned the most income in their holdings has the following characteristics: age above 42 years, more than 25 years of experience, owner of the farm and dedicated full time to the farm. In all the regions, the most profitable holdings used integrated pest management systems and grafts.

The combination of the Almería-type greenhouse and sand plots is still after 50 years in excellent condition since it is the most profitable alternative in most of the cases. The most profitable structures have increased their height and have roof ventilation on at least half of the ridges.

The importance of the cooperative movement has also been reflected in the most profitable holdings, in which farmers have belonged to the cooperative that sells their fruits and vegetables for over 10 years.

Moreover, all farms of maximum profitability are subject to several certification systems.

5.2. Average profile of the holding with the highest productive yields by season according to the combination of crops and cycles

In this section, we present the average profile of the ten holdings with the highest productive yield (kg m^{-2}) according to the crops sown each season. In all cases, the data from the most recent three seasons were analysed (from 2010/11 to 2012/13).

A summary data sheet of the twelve most frequently observed crop combinations in the sample was created.

The Almería-type greenhouse continues to show good performance for all the crops considered in the present analysis. Only the long cycles, especially those of tomato, have a relevant number of multi-span structure types, which are also used for certain specialty crops, such as cucumber, in which heating is sometimes used.

Table 29. Profile of the holdings with the highest gross estimated income in Campo de Dalías

GROSS RETURN

Estimation	Reported data by farmer for the 2012/2013 campaign				
Estimated average income (μ_3) €/m²	Average income €/m²	Average running cost €/m²	Gross margin €/m²	Have you been granted any type of subsidy?	Have you been granted any type of financing?
6.9 shorts cycles 10.2 long cycles	9.5	6.6	2.9	Yes (6/10) - FVPO	partial (4/10)

FARMER PROFILE

Average age	Experience	Land ownership	Level of studies	Dedication
46	27	Owner	Primary studies	Full time farmer

CROP DATA

Seasons	Crop(s)	Cycle(s)	Average yield (kg/m²)	Crop lines orientation	Plants by m²	Are foliar analyses carried out?	Do you use alternative systems to phytosanitary products?	Do you use grafts?
2010/2011 to 2012/2013	Autumn: Tomato; California pepper; cucumber Spring: Zucchini; melon; watermelon Long: Ramiro type pepper; tomato	Short and long	Autumn: 14.0 tomato; 7.8 california pepper; 12.5 cucumber Spring: 7.5 zucchini; 8.0 watermelon; 5.3 melon Long: 18.0 pepper type ramiro; 18.0 tomato; 9.0 tomato *cherry*	Longitudinal (8/10) Perpendicular (2/10)	1.1 tomato 0.6 cucumber 1.4 pepper 0.3 watermelon	Yes, coop.	Integrated control	Yes (tomato and watermelon)

SOIL DATA

Soil type	Is soil disinfected?	Is broadcasting performed?	Surface and frequency	Type of fertilizer	Is soil analysed?	Do you add humic acids?
Hydroponic (4/10) Sanded (6/10)	Yes, solarisation and disinfection every year	Yes (6/10)	Banding / 3-4 years	Sheep (4/10) Prepared sacks (2/10)	Yes	Yes (9/10)

IRRIGATION SYSTEM

Water or farm well (%)	Total average cost (€/m³)	Total average conductivity (dS/m)
0	0.3	0.9

Table 29 (cont.). Profile of the holdings with the highest gross estimated income in Campo de Dalías

MARKETING DATA

Where is your product sold?	Are all of your products brought to the same location?	Are you a member of a cooperative?	How many years?	Do you receive technical advice?	Type of advice	Do you prepare the products yourself?	Of harvest time dedicated to preparing the products? (%)	Certification systems
Cooperative (8/10) SAT (2/10)	Yes	Yes	>10	Always	Cooperative	No (8/10)		Global Gap, UNE, Naturane and integrated prod.

DATA ON THE GREENHOUSE STRUCTURE

Age (years)	Greenhouse type	Orientation	Surface (m²)	Cover material	Type of support	Maximum height (ridge)	Minimum height (Bellow channel)
11	*Raspa y amagado* (5/10) Asymmetrical (2/10) Multispan (2/10) Flat-roof (1/10)	North-South (7/10)	14,242	Three-layer plastic	Metal tubes	4.6 (R-A) 4.4 (Asymmetrical) 7.7 (Multispan) 3.5 (Flat-roof)	3.6 (R-A) 3.5 (Asymmetrical) 5.5 (Multispan) 3.5 (Flat-roof)

Type of roof window	Windows per span (%)	Surface with roof ventilation (%)	Type of lateral window	Number of lateral windows	Surface with lateral ventilation (%)	Total ventilation (%)
Flap ventilators (5/10) Roof openings (2/10) Superzenith (2/10)	62.3	4.9	Sliding bands (4/10) Sliding ventilators (3/10) Rolling ventilators (2/10)	4 (8/10)	6.5	11.4

CLIMATE CONTROL SYSTEM

Do you use a climate controller?	Do you have a forced ventilation system installed?	Do you have a water evaporative cooling system installed?	Heating system?
No	No	No	No

LABOUR DATA

Own or contracted?	Relationship with the contracted personnel?	Use of contracted personnel
Contracted (8/10)	30 % temporary; 47 % permanent discontinuous	Collection

Table 30. Profile of the holdings with the highest gross estimated income in Bajo Andarax

GROSS RETURN					
Estimation	**Reported data by farmer for the 2012/2013 campaign**				
Estimated average income (μ_3) €/m²	**Average income €/m²**	**Average running costs €/m²**	**Gross margin €/m²**	**Have you been granted any type of subsidy?**	**Have you been granted any type of financing?**
8.0 shorts cycles 11.1 long cycle	8.1	4.6	3.5	Yes (6/10) - FVPO	Partial (4/10)

FARMER PROFILE				
Average age	**Experience**	**Land ownership**	**Level of studies**	**Dedication**
46	24	Owner	Vocational training	Full time farmer

CROP DATA								
Seasons	**Crop(s)**	**Cycle(s)**	**Average yield (kg/m²)**	**Crop lines orientation**	**Plants by m²**	**Are foliar analyses carried out?**	**Do you use alternative systems to phytosanitary products?**	**Do you use grafts?**
2010/2011 to 2012/2013	Autumn: tomato Spring: tomato Long: tomato; *cherry* tomato	2 shorts (6/10) 1 long (4/10)	Autumn: 9.0 tomato Spring: 11.4 tomato Long: 17.9 tomato; 14.0 *cherry* tomato	Longitudinal (4/10) Perpendicular (5/10)	1.4 tomato	Yes, coop.	Integrated control; biological control	Yes (tomato)

SOIL DATA						
Soil type	**Is soil disinfected?**	**Is broadcasting performed?**	**Surface and frequency**	**Type of fertilizer**	**Is soil analysed?**	**Do you add humic acids?**
Hydroponic (1/10) Sanded (9/10)	Yes, disinfection every 2 years	Yes (5/10)	Banding / 2-3 years	Sheep and cow	Yes	Yes (7/10)

IRRIGATION SYSTEM		
Water or farm well (%)	**Total average cost (€/m³)**	**Total average conductivity (dS/m)**
13.0	0.3	2.8

Table 30 (cont.). Profile of the holdings with the highest gross estimated income in Bajo Andarax

MARKETING DATA								
Where is your product sold?	**Are all of your products brought to the same location?**	**Are you a member of a cooperative?**	**How many years?**	**Do you receive technical advice?**	**Type of advice**	**Do you prepare the products yourself?**	**Of harvest time dedicated to preparing the products? (%)**	**Certification systems**
Cooperative	Yes	Yes	>10	Always	Cooperative	Yes (6/10)	35.0	Global Gap, UNE, Naturane and integrated prod.

DATA ON THE GREENHOUSE STRUCTURE							
Age (years)	**Greenhouse type**	**Orientation**	**Surface (m²)**	**Cover material**	**Type of support**	**Maximum height (ridge)**	**Minimum height (Bellow channel)**
12	*Raspa y amagado* (5/10) Asymmetrical (2/10) Flat-roof (3/10)	North-South (5/10)	8,025	Three-layer plastic	Metal tubes	4.9 (*Raspa y amagado*) 4.6 (Asymmetrical) 3.3 (Flat-roof)	3.7 (*Raspa y amagado*) 3.3 (Asymmetrical) 3.3 (Flat-roof)
Type of roof window	**Windows per span (%)**	**Surface with roof ventilation (%)**	**Type of lateral window**	**Number of lateral windows**	**Surface with lateral ventilation (%)**	**Total ventilation (%)**	
Flap ventilator (6/10) Roof openings (3/10)	67.2	6.1	Bandas deslizantes	4	12.2	18.3	

CLIMATE CONTROL SYSTEM			
Do you use a climate controller?	**Do you have a forced ventilation system installed?**	**Do you have a water evaporative cooling system installed?**	**Heating system?**
No	No	No	No

LABOUR DATA		
Own or contracted?	**Relationship with the contracted personnel?**	**Use of contracted personnel**
Contracted and own	12 % temporary; 68 % permanent disc.	Collection

Table 31. Profile of the holdings with the highest gross estimated income in Campo de Níjar

GROSS RETURN					
Estimation	Reported data by farmer for the 2012/2013 campaign				
Estimated average income (μ_3) €/m²	Average income €/m²	Average running costs €/m²	Gross margin €/m²	Have you been granted any type of subsidy?	Have you been granted any type of financing?
5,6 Short cycle 13,9 Long cycle	8.4	5.4	3.0	yes (7/10) - FVPO	Frequent (7/10)

FARMER PROFILE				
Average age	Experience	Land ownership	Level of studies	Dedication
42	25	Owner	Primary studies	Full time farmer

CROP DATA								
Seasons	Crop(s)	Cycle(s)	Average yield (kg/m²)	Crop lines orientation	Plants by m²	Are foliar analyses carried out?	Do you use alternative systems to phytosanitary products?	Do you use grafts?
2010/2011 to 2012/2013	Autumn: tomato Spring: tomato; Watermelon Long: *cherry* tomato	Short and long cycles	Autumn: 7.7 tomato; 6.0 *cherry* tomato Spring: 7.2 watermelon Long: 13.5 *cherry* tomato	Longitudinal (7/10) Perpendicular (3/10)	0.9 tomato 0.6 cucumber 0.3 watermelon	Yes, coop. (6/10)	Colour traps; integrated control	Yes (tomato and watermelon)

SOIL DATA						
Soil type	Is soil disinfected?	Is broadcasting performed?	Surface and frequency	Type of fertilizer	Is soil analysed?	Do you add humic acids?
Hydroponic (1/10) Sanded (9/10)	Yes, solarisation and disinfection every 2 years	Yes (5/10)	Banding / every 5 years	Sheep (3/10) Prepared sacks (2/10)	Yes	Yes

IRRIGATION SYSTEM		
Water or farm well (%)	Total average cost (€/m³)	Total average conductivity (dS/m)
10.0	0.2	2.3

Table 31 (cont.). Profile of the holdings with the highest gross estimated income in Campo de Níjar

MARKETING DATA

Where is your product sold?	Are all of your products brought to the same location?	Are you a member of a cooperative?	How many years?	Do you receive technical advice?	Type of advice	Do you prepare the products yourself?	Of harvest time dedicated to preparing the products? (%)	Certification systems
Cooperative (8/10) SAT (2/10)	Yes	Yes	>10	Always	Cooperative	No (8/10)		Global Gap, UNE, Naturane y P. I.

DATA ON THE GREENHOUSE STRUCTURE

Age (years)	Greenhouse type	Orientation	Surface (m²)	Cover material	Type of support	Maximum height (ridge)	Minimum height (Bellow channel)
9	*Raspa y amagado* (7/10) Asymmetrical (2/10) Multispan (1/10)	East-West (7/10)	11,860	Three-layer plastic	Metal tubes	5.1 (*Raspa y amagado*) 5.0 (Asymmetrical) 6.6 (Multispan)	4.2 (*Raspa y amagado*) 4.5 (Asymmetrical) 4.5 (Multispan)

Type of roof window	Windows per span (%)	Surface with roof ventilation (%)	Type of lateral window	Number of lateral windows	Surface with lateral ventilation (%)	Total ventilation (%)
Flap ventilator (10/10)	51.7	5.3	Sliding bands (7/10) Sliding ventilators (2/10) Rolling ventilators (1/10)	4 (8/10)	13.0	18.3

CLIMATE CONTROL SYSTEM

Do you use a climate controller?	Do you have a forced ventilation system installed?	Do you have a water evaporative cooling system installed?	Heating system?
No (9/10) Yes (1/10)	No (9/10) Yes, inside fan (1/10)	No (9/10) Yes, fogging (1/10)	No (8/10) Yes (2/10)

LABOUR DATA

Own or contracted?	Relationship with the contracted personnel?	Use of contracted personnel
Contracted	23 % temporary; 75 % permanent disc.	Collection

Table 32. Profile of the holdings with the highest gross estimated income in Bajo Almanzora

GROSS RETURN					
Estimation	Reported data by farmer for the 2012/2013 campaign				
Estimated average income (μ_3) €/m²	Average income €/m²	Average running costs €/m²	Gross margin €/m²	Have you been granted any type of subsidy?	Have you been granted any type of financing?
4.9 short cycles 6.83 long cycles	4.6	3.1	1.5	Yes (2/9) - FVPO	Frequent (7/10)

FARMER PROFILE				
Average age	Experience	Land ownership	Level of studies	Dedication
53	31	Owner	University	Other professional activities

CROP DATA								
Seasons	Crop(s)	Cycle(s)	Average yield (kg/m²)	Crop lines orientation	Plants by m²	Are foliar analyses carried out?	Do you use alternative systems to phytosanitary products?	Do you use grafts?
2010/2011 to 2012/2013	Autumn: tomato; cucumber Spring: tomato; eggplant; watermelon Long: tomato; *cherry* tomato	Short and long	Autumn: 7.50 tomato; 9.0 cucumber Spring: 11.0 tomato; 6.8 eggplant Long: 17.5 tomato; 12.0 *cherry* tomato	Longitudinal (1/9) Perpendicular (8/9)	1.3 tomato 0.6 cucumber 0.5 eggplant 0.6 watermelon	Yes, coop. (7/9)	Colour traps; integrated control	Yes (tomato and eggplant)

SOIL DATA						
Soil type	Is soil disinfected?	Is broadcasting performed?	Surface and frequency	Type of fertilizer	Is soil analysed?	Do you add humic acids?
Native (6/9) Sanded (3/9)	Yes, solarisation every year	Yes (4/9)	Banding / every 3-4 years	Prepared sacks (4/9)	Yes	Yes

IRRIGATION SYSTEM		
Water or farm well (%)	Total average cost (€/m³)	Total average conductivity (dS/m)
0	0.4	2.2

Table 32 (cont.). Profile of the holdings with the highest gross estimated income in Bajo Almanzora

MARKETING DATA

Where is your product sold?	Are all of your products brought to the same location?	Are you a member of a cooperative?	How many years?	Do you receive technical advice?	Type of advice	Do you prepare the products yourself?	Of harvest time dedicated to preparing the products? (%)	Certification systems
Cooperative (8/9) Private (1/9)	Yes (8/9)	Yes (6/9)	>10	Always	Cooperative; supplies	No (6/8)		Global Gap and UNE

DATA ON THE GREENHOUSE STRUCTURE

Age (years)	Greenhouse type	Orientation	Surface (m^2)	Cover material	Type of support	Maximum height (ridge)	Minimum height (Bellow channel)
16	*Raspa y amagado* (7/9) Asymmetrical (2/9)	North-South (4/9) East-West (5/9)	7,289	Three-layer plastic	Metal tubes	4,5 (R-A) 4,6 (Asymmetrical)	3,4 (R-A) 3,6 (Asymmetrical)

Type of roof window	Windows per span (%)	Surface with roof ventilation (%)	Type of lateral window	Number of lateral windows	Surface with lateral ventilation (%)	Total ventilation (%)
Flap ventilators (4/9) Roof openings (5/9)	87,0	4,04	Sliding band (7/9) Sidewall rolling (2/9)	4 (8/9)	9.6	13.6

CLIMATE CONTROL SYSTEM

Do you use a climate controller?	Do you have a forced ventilation system installed?	Do you have a water evaporative cooling system installed?	Heating system?
No	No	No	No (8/9) Yes (1/9)

LABOUR DATA

Own or contracted?	Relationship with the contracted personnel?	Use of contracted personnel
Contracted (7/9)	16 % temporary; 33 % permanent disc.	All tasks

Table 33. Profile of the holdings with the highest average production yield for two crops of short-cycle tomato by season

Locations	Bajo Andarax	Campo de Dalías	Campo de Níjar	Bajo Almanzora
Number	0	1	1	0

FARMER PROFILE

Average age	Experience	Land ownership	Level of studies	Dedication
62	38	Owner	Primary	

CROP DATA

Seasons	Crop(s)	Cycle(s)	Average yield (kg/m²)	Crop lines orientation	Plants by m²	Are foliar analyses carried out?	Do you use alternative systems to phytosanitary products?	Do you use grafts?
2010/2011 to 2012/2013	Autumn: tomato Spring: tomato	2 shorts	Autumn: 7,8 Spring: 12,5	North - Sourth	1.0	Yes, coop.	integrated control	Yes (tomato)

SOIL DATA

Soil type	Is soil disinfected?	Is broadcasting performed?	Surface and frequency	Type of fertilizer	Is soil analysed?	Do you add humic acids?
Sanded (2/2)	Yes, solarisation and y disinfection every year	Yes (1/2)	Banding / 3-4 años	Sheep (1/2)	Yes	Yes

IRRIGATION SYSTEM

water of farm well (%)	Total average cost €/m³	Total average conductivity (dS/m)
0	0.2	1.2

MARKETING DATA

Where is your product sold?	Are all of your products brought to the same location?	Are you a member of a cooperative?	How many years?	Do you receive technical advice?	Type of advice	Do you prepare the products yourself?	harvest time dedicated to preparing the products? (%)	Certification systems
SAT	Always	Yes	>10	Always	Cooperative	No (2/2)		UNE

Table 33 (cont.). Profile of the holdings with the highest average production yield for two crops of short-cycle tomato by season

DATA ON THE GREENHOUSE STRUCTURE

Age (years)	Greenhouse type	Orientation	Surface (m²)	Cover material	Type of support	Maximum height (ridge)	Minimum height (below channel)
19	*Raspa y amagado* (1/2) Flat roof (1/2)	North a Sourth (1/2)	11,800	Three-layer plastic	Metal tubes	5.0 (*Raspa*) 2.6 (Flat-roof)	4.7 (*Raspa*) 2.6 (Flat-roof)

Type of roof window	windows per span (%)	surface with roof ventilation (%)	Type of side vents	Number of side vents	surface with side ventilation (%)	total ventilation (%)
Flap ventilators (1/2) Rolling ventilators (1/2)	47.0	7.4	Sliding bands (10/10)	4	9.0	16.4

CLIMATE CONTROL SYSTEM

Do you use a climate controller?	Do you have a forced ventilation system installed?	Do you have a water evaporative cooling system installed?	Heating system?
No	No	Yes, nebulisation (1/2)	No

LABOUR DATA

Own or contracted?	Relationship with the contracted personnel?	Use of contracted personnel
Contracted and own	36 % temporary; 64 % permanent disc.	Collection

Table 34. Profile of the holdings with the highest average production yield for one crop of long-cycle tomato by season

Locations	Bajo Andarax	Campo de Dalías	Campo de Níjar	Bajo Almanzora
Number	4	1	4	1

FARMER PROFILE				
Average age	Experience	Land ownership	Level of studies	Dedication
46	24	Owner	Primary	full time farmer

CROP DATA								
Seasons	Crop(s)	Cycle(s)	Average yield (kg/m²)	Crop lines orientation	Plants by m²	Are foliar analyses carried out?	Do you use alternative systems to phytosanitary products?	Do you use grafts?
2010/2011 to 2012/2013	Long cycle tomato	Long	20,9	North - South (8/10)	1,5	Yes, coop. (4/10)	Integrated control	Yes (tomato)

SOIL DATA						
Soil type	Is soil disinfected?	Is broadcasting performed?	Surface and frequency	Type of fertilizer	Is soil analysed?	Do you add humic acids?
Sanded (7/10) Hydroponic (2/10)	Yes, solarisation and disinfection every year	Yes (6/10)	Banding / 3-4 years	Manure mixture	Yes	Yes

IRRIGATION SYSTEM		
water of farm well (%)	Total average cost €/m³	Total average conductivity (dS/m)
23	0,3	2,3

MARKETING DATA								
Where is your product sold?	Are all of your products brought to the same location?	Are you a member of a cooperative?	How many years?	Do you receive technical advice?	Type of advice	Do you prepare the products yourself?	harvest time dedicated to preparing the products? (%)	Certification systems
Cooperative and SAT	Always	Yes	> 10	Always	Cooperative; Supplies	Yes (6/10)	23,0	Global, GAP, UNE-155.000, Naturane and integrated prod.

Table 34 (cont.). Profile of the holdings with the highest average production yield for one crop of long-cycle tomato by season

DATA ON THE GREENHOUSE STRUCTURE							
Age (years)	**Greenhouse type**	**Orientation**	**Surface (m^2)**	**Cover material**	**Type of support**	**Maximum height (ridge)**	**Minimum height (below channel)**
10	*Raspa y amagado* (6/10) Cylindrical multispan (4/10)	North - South (9/10)	9,093	Three-layer plastic	Metal tubes	4.7 (*Raspa*) 5.8 (Multispan)	3.5 (*Raspa*) 4.3 (Multispan)
Type of roof window	**windows per span (%)**	**surface with roof ventilation (%)**	**Type of side vents**	**Number of side vents**	**surface with side ventilation (%)**	**total ventilation (%)**	
Half arch (4/10) Flap ventilators (3/10)	58.0	8.6	Rolling vents (5/10) Flap vents (3/10)	4 (8/10)	9.2	17.8	

CLIMATE CONTROL SYSTEM			
Do you use a climate controller?	**Do you have a forced ventilation system installed?**	**Do you have a water evaporative cooling system installed?**	**Heating system?**
No	No	No	No (6/10); Air (4/10)

LABOUR DATA		
Own or contracted?	**Relationship with the contracted personnel?**	**Use of contracted personnel**
Contracted (8/10)	45 % temporary; 34 % permanent disc.	All tasks

Table 35. Profile of the holdings with the highest average production yield for two short-cycle crops of pepper and melon by season

Locations	Bajo Andarax	Campo de Dalías	Campo de Níjar	Bajo Almanzora
Number	0	10	0	0

FARMER PROFILE				
Average age	Experience	Land ownership	Level of studies	Dedication
44	23	Owner	Primary studies	Full time farmer

CROP DATA								
Seasons	Crop(s)	Cycle(s)	Average yield (kg/m^2)	Crop lines orientation	Plants by m^2	Are foliar analyses carried out?	Do you use alternative systems to phytosanitary products?	Do you use grafts?
2010/2011 to 2012/2013	Autumn: California pepper Spring: Melon	2 shorts	Autumn: 7.6 Spring: 4.6	North - South	1.7 pepper 0.7 watermelon	Yes, coop.	Integrated control; Colour traps	No

SOIL DATA						
Soil type	Is soil disinfected?	Is broadcasting performed?	Surface and frequency	Type of fertilizer	Is soil analysed?	Do you add humic acids?
Sanded (9/10) Hydroponic (1/10)	Yes, disinfection every year	Yes (6/10)	Banding / 3-4 years	Sheeps (5/10) Sacks (1/10)	Yes	Yes (8/10)

IRRIGATION SYSTEM		
water of farm well (%)	Total average cost €/m^3	Total average conductivity (dS/m)
0	0.3	0.9

MARKETING DATA								
Where is your product sold?	Are all of your products brought to the same location?	Are you a member of a cooperative?	How many years?	Do you receive technical advice?	Type of advice	Do you prepare the products yourself?	harvest time dedicated to preparing the products? (%)	Certification systems
Cooperative y SAT	Always	Yes	> 10	Always	Cooperative	No (9/10)		Global, GAP, UNE-155.000, Naturane and integrated prod

Table 35 (cont.). Profile of the holdings with the highest average production yield for two short-cycle crops of pepper and melon by season

DATA ON THE GREENHOUSE STRUCTURE

Age (years)	Greenhouse type	Orientation	Surface (m^2)	Cover material	Type of support	Maximum height (ridge)	Minimum height (below channel)
17	*Raspa y amagado* (5/10) Flat-roof (4/10) Asymmetrical (1/10)	North - South (7/10)	12,304	Three-layer plastic	Metal tubes	4.0 (*Raspa*) 3.4 (Flat-roof) 4.0 (Asymmetrical)	3.1 (*Raspa*) 4.4 (Flat-roof) 3.0 (Asymmetrical)

Type of roof window	windows per span (%)	surface with roof ventilation (%)	Type of side vents	Number of side vents	surface with side ventilation (%)	total ventilation (%)
Flap ventilators (6/10)	47	4.6	Sliding bands (10/10)	4	7.3	13.4

CLIMATE CONTROL SYSTEM

Do you use a climate controller?	Do you have a forced ventilation system installed?	Do you have a water evaporative cooling system installed?	Heating system?
No	No	Yes, fogging (5/10)	No

LABOUR DATA

Own or contracted?	Relationship with the contracted personnel?	Use of contracted personnel
Contracted (8/10)	44 % temporary; 44 % permanent disc.	All tasks

Table 36. Profile of the holdings with the highest average production yield for two short-cycle crops of pepper and watermelon by season

Locations	Bajo Andarax	Campo de Dalías	Campo de Níjar	Bajo Almanzora
Number	0	8	0	0

FARMER PROFILE				
Average age	**Experience**	**Land ownership**	**Level of studies**	**Dedication**
52	31	Owner	Primary studies	Full time farmer

CROP DATA								
Seasons	**Crop(s)**	**Cycle(s)**	**Average yield (kg/m^2)**	**Crop lines orientation**	**Plants by m^2**	**Are foliar analyses carried out?**	**Do you use alternative systems to phytosanitary products?**	**Do you use grafts?**
2010/2011 to 2012/2013	Autumn: California pepper Spring: Watermelon	2 shorts	Autumn: 7.4 Spring: 5.9	North - South	1.6 pepper 0.3 watemelon	Yes, coop.	Integrated control; Colour traps	Yes (watermelon)

SOIL DATA						
Soil type	**Is soil disinfected?**	**Is broadcasting performed?**	**Surface and frequency**	**Type of fertilizer**	**Is soil analysed?**	**Do you add humic acids?**
Sanded (6/8) Hydroponic (2/8)	Yes, solarisation and disinfection every year	No (7/8)			Yes	Yes

IRRIGATION SYSTEM		
water of farm well (%)	**Total average cost €/m^3**	**Total average conductivity (dS/m)**
0	0.3	0.8

MARKETING DATA								
Where is your product sold?	**Are all of your products brought to the same location?**	**Are you a member of a cooperative?**	**How many years?**	**Do you receive technical advice?**	**Type of advice**	**Do you prepare the products yourself?**	**harvest time dedicated to preparing the products? (%)**	**Certification systems**
Cooperative and SAT	Yes (7/8)	Yes (4/8)	5 - 10 (4/8)	Always	Cooperative	No (6/8)		UNE-155.00, Naturane and integrated prod.

Table 36 (cont.). Profile of the holdings with the highest average production yield for two short-cycle crops of pepper and watermelon by season

DATA ON THE GREENHOUSE STRUCTURE

Age (years)	Greenhouse type	Orientation	Surface (m²)	Cover material	Type of support	Maximum height (ridge)	Minimum height (below channel)
9	*Raspa y amagado* (7/8) Flat-roof (1/8)	Norh - South	14,588	Three-layer plastic	Metal tubes	4.4 (*Raspa*) 3.5 (Flat-roof)	3,7 (*Raspa*) 3,5 (Flat-roof)

Type of roof window	windows per span (%)	surface with roof ventilation (%)	Type of side vents	Number of side vents	surface with side ventilation (%)	total ventilation (%)
Flat ventilators (6/8) Roof openings (2/8)	41	6.3	Slidings bands (5/8)	4	8.2	14.4

CLIMATE CONTROL SYSTEM

Do you use a climate controller?	Do you have a forced ventilation system installed?	Do you have a water evaporative cooling system installed?	Heating system?
No	No	Yes, fogging (1/8)	No

LABOUR DATA

Own or contracted?	Relationship with the contracted personnel?	Use of contracted personnel
Contracted and own	23 % temporary; 17 % permanent disc.	Collection

Table 37. Profile of the holdings with the highest average production yield for one long-cycle crop of pepper

Locations	Bajo Andarax	Campo de Dalías	Campo de Níjar	Bajo Almanzora
Number	0	9	1	0

FARMER PROFILE				
Average age	**Experience**	**Land ownership**	**Level of studies**	**Dedication**
43	20	Owner	University	Full timer farmer

CROP DATA								
Seasons	**Crop(s)**	**Cycle(s)**	**Average yield (kg/m^2)**	**Crop lines orientation**	**Plants by m^2**	**Are foliar analyses carried out?**	**Do you use alternative systems to phytosanitary products?**	**Do you use grafts?**
2010/2011 to 2012/2013	Long cycle Pepper	Long	Ramiro type 14.4 Sweet Italian 11.8	North - South (6/10)	1.8	Yes, coop. (6/10)	Integrated control; Colour traps	No

SOIL DATA						
Soil type	**Is soil disinfected?**	**Is broadcasting performed?**	**Surface and frequency**	**Type of fertilizer**	**Is soil analysed?**	**Do you add humic acids?**
Sanded (10/10)	Yes, solarisation and disinfection every year	Yes (5/10)	All surface (4/10) / 3-4 years	Mixture (4/10)	Yes (8/10)	Yes (9/10)

IRRIGATION SYSTEM		
water of farm well (%)	**Total average cost €/m^3**	**Total average conductivity (dS/m)**
12	0.4	1.0

MARKETING DATA								
Where is your product sold?	**Are all of your products brought to the same location?**	**Are you a member of a cooperative?**	**How many years?**	**Do you receive technical advice?**	**Type of advice**	**Do you prepare the products yourself?**	**harvest time dedicated to preparing the products? (%)**	**Certification systems**
Cooperative (4/10) Private (4/10)	Always	No (6/10) Yes (4/10)	> 10	Yes	Supplies	No		UNE-155.000, Naturane and integrated prod.

Table 37 (cont.). Profile of the holdings with the highest average production yield for one long-cycle crop of pepper

DATA ON THE GREENHOUSE STRUCTURE							
Age (years)	**Greenhouse type**	**Orientation**	**Surface (m²)**	**Cover material**	**Type of support**	**Maximum height (ridge)**	**Minimum height (below channel)**
11	*Raspa y amagado* (7/10) Flat-roof (2/10) Asymmetrical (1/10)	North - South (8/10)	11,250	Three-layer plastic	Tubo metálico	4,1 (*Raspa*) 2,9 (Flat-roof) 4,2 (Asymmetrical)	3,6 (*Raspa*) 2,9 (Flat-roof) 3,2 (Asymmetrical)
Type of roof window	**windows per span (%)**	**surface with roof ventilation (%)**	**Type of side vents**	**Number of side vents**	**surface with side ventilation (%)**	**total ventilation (%)**	
Flap ventilators (7/10) Roof openings (2/10)	73.0	7.3	Slindings bandas (10/10)	4	8.3	15.6	

CLIMATE CONTROL SYSTEM			
Do you use a climate controller?	**Do you have a forced ventilation system installed?**	**Do you have a water evaporative cooling system installed?**	**Heating system?**
No (9/10) Yes (1/10)	No (9/10) Yes (1/10) - extractors	No (8/10) Yes, Low pressure fogging (2/10)	No

LABOUR DATA		
Own or contracted?	**Relationship with the contracted personnel?**	**Use of contracted personnel**
Contracted	40 % temporary; 31 % permanent disc.	Todas las labores

Table 38. Profile of the holdings with the highest average production yield for two short-cycle crops of cucumber and watermelon by season

Locations	Bajo Andarax	Campo de Dalías	Campo de Níjar	Bajo Almanzora
Number	0	4	0	0

FARMER PROFILE				
Average age	**Experience**	**Land ownership**	**Level of studies**	**Dedication**
52	34	Owner	Primary studies	Full time farmer

CROP DATA								
Seasons	**Crop(s)**	**Cycle(s)**	**Average yield (kg/m^2)**	**Crop lines orientation**	**Plants by m^2**	**Are foliar analyses carried out?**	**Do you use alternative systems to phytosanitary products?**	**Do you use grafts?**
2010/2011 to 2012/2013	Autumn: Pepper Spring: Watermelon	2 shorts	Autumn: 9.3 Spring: 5.6	North - South (2/4)	1.1 pepper 0.5 watermelon	Yes, coop.	Integrated control; Colour traps	Yes (Watermelon)

SOIL DATA						
Soil type	**Is soil disinfected?**	**Is broadcasting performed?**	**Surface and frequency**	**Type of fertilizer**	**Is soil analysed?**	**Do you add humic acids?**
Sanded (2/4) Hydroponic (2/4)	Yes, disinfection every year (2/4)	Yes (3/4)	Banding / 2-3 years	Prepared sacks (3/4) Sheep (1/4)	Yes (2/4)	Yes

IRRIGATION SYSTEM		
water of farm well (%)	**Total average cost €/m^3**	**Total average conductivity (dS/m)**
0	0.2	1.1

MARKETING DATA								
Where is your product sold?	**Are all of your products brought to the same location?**	**Are you a member of a cooperative?**	**How many years?**	**Do you receive technical advice?**	**Type of advice**	**Do you prepare the products yourself?**	**harvest time dedicated to preparing the products? (%)**	**Certification systems**
Cooperative	Yes	Yes	> 10	Always	Cooperative	No		Global GAP, UNE-155.000, Naturane and integrated prod.

Table 38 (cont.). Profile of the holdings with the highest average production yield for two short-cycle crops of cucumber and watermelon by season

DATA ON THE GREENHOUSE STRUCTURE

Age (years)	Greenhouse type	Orientation	Surface (m^2)	Cover material	Type of support	Maximum height (ridge)	Minimum height (below channel)
15	*Raspa y amagado* (4/4)	North - South	11,175	Three-layer plastic	Metal tubes	3.9	3.1

Type of roof window	windows per span (%)	surface with roof ventilation (%)	Type of side vents	Number of side vents	surface with side ventilation (%)	total ventilation (%)
Flap ventilators	53	3.8	Slidings bands	4	10.1	14.5

CLIMATE CONTROL SYSTEM

Do you use a climate controller?	Do you have a forced ventilation system installed?	Do you have a water evaporative cooling system installed?	Heating system?
No (3/4) Thermal screen (1/4)	No	Yes, fogging (1/4) No (3/4)	No

LABOUR DATA

Own or contracted?	Relationship with the contracted personnel?	Use of contracted personnel
Contracted	35 % temporary; 65 % permanent disc.	Collecting and trellis preparation

Table 39. Profile of the holdings with the highest average production yield for two short-cycle crops of cucumber and melon by season

Locations	Bajo Andarax	Campo de Dalías	Campo de Níjar	Bajo Almanzora
Number	0	10	0	0

FARMER PROFILE				
Average age	**Experience**	**Land ownership**	**Level of studies**	**Dedication**
48	29	Owner	Primary studies	Full time farmer

CROP DATA								
Seasons	**Crop(s)**	**Cycle(s)**	**Average yield (kg/m²)**	**Crop lines orientation**	**Plants by m²**	**Are foliar analyses carried out?**	**Do you use alternative systems to phytosanitary products?**	**Do you use grafts?**
2010/2011 to 2012/2013	Autumn: Pepper Spring: Melon	2 Shorts	Autumn: 10.6 Spring: 5.3	North - South (7/10)	0.8 pepper 0.7 melon	Yes, coop.	Integrated control; biological control	No

SOIL DATA						
Soil type	**Is soil disinfected?**	**Is broadcasting performed?**	**Surface and frequency**	**Type of fertilizer**	**Is soil analysed?**	**Do you add humic acids?**
Sanded (10/10)	Yes, disinfection every year (9/10)	Yes (7/10)	Banding / 2-3 years	Prepared sacks (3/10) Sheep (3/10) Compost (1/10)	Yes (8/10)	Yes (8/10)

IRRIGATION SYSTEM		
water of farm well (%)	**Total average cost €/m³**	**Total average conductivity (dS/m)**
2.0	1.1	1.0

MARKETING DATA								
Where is your product sold?	**Are all of your products brought to the same location?**	**Are you a member of a cooperative?**	**How many years?**	**Do you receive technical advice?**	**Type of advice**	**Do you prepare the products yourself?**	**harvest time dedicated to preparing the products? (%)**	**Certification systems**
Cooperative and SAT	Yes	Yes	> 10	Always	Cooperative	No (8/10)		UNE-155.000, Naturane and integrated prod.

Table 39 (cont.). Profile of the holdings with the highest average production yield for two short-cycle crops of cucumber and melon by season

DATA ON THE GREENHOUSE STRUCTURE

Age (years)	Greenhouse type	Orientation	Surface (m²)	Cover material	Type of support	Maximum height (ridge)	Minimum height (below channel)
13	*Raspa y amagado* (7/4) Flat-roof (1/10) Asymmetrical (1/10) Multispan (1/10)	North - South	12,160	Three-layer plastic	Metal tubes	4,2 (raspa) 2,7 (Flat-roof) 5,3 (Asymmetrical) 6,5 (Multispan)	3,4 (raspa) 2,7 (Flat-roof) 3,5 (Asymmetrical) 4,5 (Multispan)

Type of roof window	windows per span (%)	surface with roof ventilation (%)	Type of side vents	Number of side vents	surface with side ventilation (%)	total ventilation (%)
Flap ventilators (4/10) Roof openings (2/10) Pyramidal (1/10) Half-arch (1/10)	43.0	3.6 (*Raspa y amagado*) 6.4 (multispan)	Slidings bands	4	8,4 (*Raspa y amagado*) 7,4 (multispan)	12,0 (*Raspa y amagado*) 13,8 (multispan)

CLIMATE CONTROL SYSTEM

Do you use a climate controller?	Do you have a forced ventilation system installed?	Do you have a water evaporative cooling system installed?	Heating system?
No (8/10) Thermal screen/plástico (2/10)	No	Yes, fogging (7/10) No (3/10)	No

LABOUR DATA

Own or contracted?	Relationship with the contracted personnel?	Use of contracted personnel
Contracted	1 % temporary; 64 % permanent disc.	All tasks

Table 40. Profile of the holdings with the highest average production yield for two short-cycle crops of courgette by season

Locations	Bajo Andarax	Campo de Dalías	Campo de Níjar	Bajo Almanzora
Number	0	10	0	0

FARMER PROFILE				
Average age	**Experience**	**Land ownership**	**Level of studies**	**Dedication**
45	24	Owner	Primary studies	Full time farmer

CROP DATA								
Seasons	**Crop(s)**	**Cycle(s)**	**Average yield (kg/m²)**	**Crop lines orientation**	**Plants by m²**	**Are foliar analyses carried out?**	**Do you use alternative systems to phytosanitary products?**	**Do you use grafts?**
2010/2011 to 2012/2013	Autumn: Zucchini Spring: Zucchini	2 shorts	Autumn: 5,2 Spring: 6,4	North - South (7/10)	0.79 zucchini	Yes, coop.	Integrated control; Colour traps	No

SOIL DATA						
Soil type	**Is soil disinfected?**	**Is broadcasting performed?**	**Surface and frequency**	**Type of fertilizer**	**Is soil analysed?**	**Do you add humic acids?**
Sanded (9/10) Native (1/10)	Yes, disinfection every year	Yes (4/10)	Banding / 2-3 years	Sheep (3/10) Chicken (1/10)	Yes (7/10)	Yes (9/10)

IRRIGATION SYSTEM		
Water of farm well (%)	**Total average cost €/m³**	**Total average conductivity (dS/m)**
5.0	0.4	1.0

MARKETING DATA								
Where is your product sold?	**Are all of your products brought to the same location?**	**Are you a member of a cooperative?**	**How many years?**	**Do you receive technical advice?**	**Type of advice**	**Do you prepare the products yourself?**	**harvest time dedicated to preparing the products? (%)**	**Certification systems**
Cooperative and SAT	Yes (9/10)	Yes (7/10)	> 10	Always	Cooperative; Suppliers	No (6/10)		UNE-155.000, Naturane and integrated prod.

Table 40 (cont.). Profile of the holdings with the highest average production yield for two short-cycle crops of courgette by season

DATA ON THE GREENHOUSE STRUCTURE

Age (years)	Greenhouse type	Orientation	Surface (m^2)	Cover material	Type of support	Maximum height (ridge)	Minimum height (below channel)
11	*Raspa y amagado* (7/10) Flat-roof (2/10) Asymmetrical (1/10)	North - South	9,100	Three-layer PE	Metal tubes	4,3 (raspa) 3,5 (Flat-roof) 4,2 (Asymmetrical)	3,4 (raspa) 3,5 (Flat-roof) 3,5 (Asymmetrical)

Type of roof window	windows per span (%)	surface with roof ventilation (%)	Type of side vents	Number of side vents	surface with side ventilation (%)	total ventilation (%)
Flap ventilators (5/10) Rolling ventilators (3/10) Sliding vents (1/10)	46,0	4,8	Sliding bans (6/10) Sliding ventilators (2/10) Flap ventilators (1/10)	4	9.7	14.5

CLIMATE CONTROL SYSTEM

Do you use a climate controller?	Do you have a forced ventilation system installed?	Do you have a water evaporative cooling system installed?	Heating system?
No	No	Yes, fogging (3/10) No (7/10)	No

LABOUR DATA

Own or contracted?	Relationship with the contracted personnel?	Use of contracted personnel
Contracted and own	17 % temporary; 43 % permanent disc.	Sowing, collection and cleaning

Table 41. Profile of the holdings with the highest average production yield for two short-cycle crops of courgette and watermelon by season

Locations	Bajo Andarax	Campo de Dalías	Campo de Níjar	Bajo Almanzora
Number	0	1	1	1

FARMER PROFILE				
Average age	**Experience**	**Land ownership**	**Level of studies**	**Dedication**
56	32	Owner	Primary studies	Full time farmer

CROP DATA								
Seasons	**Crop(s)**	**Cycle(s)**	**Average yield (kg/m^2)**	**Crop lines orientation**	**Plants by m^2**	**Are foliar analyses carried out?**	**Do you use alternative systems to phytosanitary products?**	**Do you use grafts?**
2010/2011 to 2012/2013	Autumn: Zucchini Spring: Watermelon	2 shorts	Autumn: 4,2 Primavera: 5,1	North - South (1/3)	0,8 zucchini 0,4 watermelon	Yes, coop.	Integrated control; Colour traps	Yes (Watermelon)

SOIL DATA						
Soil type	**Is soil disinfected?**	**Is broadcasting performed?**	**Surface and frequency**	**Type of fertilizer**	**Is soil analysed?**	**Do you add humic acids?**
Sanded (2/3) Native (1/3)	Yes, disinfection every year	Yes (2/3)	Banding / 2-3 years	Compost and prepared sacks	Yes	Yes

IRRIGATION SYSTEM		
Water of farm well (%)	**Total average cost €/m^3**	**Total average conductivity (dS/m)**
0	0.3	3.1

MARKETING DATA								
Where is your product sold?	**Are all of your products brought to the same location?**	**Are you a member of a cooperative?**	**How many years?**	**Do you receive technical advice?**	**Type of advice**	**Do you prepare the products yourself?**	**harvest time dedicated to preparing the products? (%)**	**Certification systems**
Public grain storage and SAT	Yes	Yes (2/3)	> 10	Always	Cooperative; Supplies	No (2/3)		Integrated control

Table 41 (cont.). Profile of the holdings with the highest average production yield for two short-cycle crops of courgette and watermelon by season

DATA ON THE GREENHOUSE STRUCTURE

Age (years)	Greenhouse type	Orientation	Surface (m^2)	Cover material	Type of support	Maximum height (ridge)	Minimum height (below channel)
10	*Raspa y amagado* (2/3) Multispan (1/3)	North - South	8,633	Three-layer plastic	Metal tubes	4,3 (*raspa*) 6,5 (Multispan)	3,0 (raspa) 4,5 (multitúnel)

Type of roof window	windows per span (%)	surface with roof ventilation (%)	Type of side vents	Number of side vents	surface with side ventilation (%)	total ventilation (%)
Flap ventilators (1/3) Roof openings (1/3) Half-arch windows (1/3)	67.0	4.4	Bandas deslizantes (2/3)	4	4.2 (R-A)	8.6

CLIMATE CONTROL SYSTEM

Do you use a climate controller?	Do you have a forced ventilation system installed?	Do you have a water evaporative cooling system installed?	Heating system?
No	No	No	No

LABOUR DATA

Own or contracted?	Relationship with the contracted personnel?	Use of contracted personnel
Contracted and own	43 % permanent intermittent; 57 % Permanent	Sowing and cleaning

Table 42. Profile of the holdings with the highest average production yield for two short-cycle crops of courgette and melon by season

Locations	Bajo Andarax	Campo de Dalías	Campo de Níjar	Bajo Almanzora
Number	0	1	0	0

FARMER PROFILE				
Average age	**Experience**	**Land ownership**	**Level of studies**	**Dedication**
32	5	Owner	Primary studies	Other professional activities

CROP DATA								
Seasons	**Crop(s)**	**Cycle(s)**	**Average yield (kg/m²)**	**Crop lines orientation**	**Plants by m²**	**Are foliar analyses carried out?**	**Do you use alternative systems to phytosanitary products?**	**Do you use grafts?**
2010/2011 to 2012/2013	Autumn: Zucchini Spring: Melon	2 shorts	Autumn: 3.5 Spring: 5.5	North - South	1.0 Zzucchini 0.5 melon	No	Colour traps	No

SOIL DATA						
Soil type	**Is soil disinfected?**	**Is broadcasting performed?**	**Surface and frequency**	**Type of fertilizer**	**Is soil analysed?**	**Do you add humic acids?**
Sanded	Yes, disinfection every year	Yes	Banding / 1-2 years	Prepared sacks	No	Yes

IRRIGATION SYSTEM		
water of farm well (%)	**Total average cost €/m³**	**Total average conductivity (dS/m)**
0	0.6	

MARKETING DATA								
Where is your product sold?	**Are all of your products brought to the same location?**	**Are you a member of a cooperative?**	**How many years?**	**Do you receive technical advice?**	**Type of advice**	**Do you prepare the products yourself?**	**harvest time dedicated to preparing the products? (%)**	**Certification systems**
Cooperative	Yes	Yes	< 2	Always	Supplies	No		Integrated producction

Table 42 (cont.). Profile of the holdings with the highest average production yield for two short-cycle crops of courgette and melon by season

DATA ON THE GREENHOUSE STRUCTURE

Age (years)	Greenhouse type	Orientation	Surface (m^2)	Cover material	Type of support	Maximum height (ridge)	Minimum height (below channel)
20	Flat-roof	North - South	6,000	Three-layer plastic	Metal tubes	3.5	3.5

Type of roof window	windows per span (%)	surface with roof ventilation (%)	Type of side vents	Number of side vents	surface with side ventilation (%)	total ventilation (%)
Roof openings		0		4	11.3	11.3

CLIMATE CONTROL SYSTEM

Do you use a climate controller?	Do you have a forced ventilation system installed?	Do you have a water evaporative cooling system installed?	Heating system?
No	No	No	No

LABOUR DATA

Own or contracted?	Relationship with the contracted personnel?	Use of contracted personnel
Own		

Table 43. Profile of the holdings with the highest average production yield for two short-cycle crops of eggplant and watermelon by season

Locations	Bajo Andarax	Campo de Dalías	Campo de Níjar	Bajo Almanzora
Number	0	1	0	0

FARMER PROFILE				
Average age	Experience	Land ownership	Level of studies	Dedication
45	25	Tenant	FP	Full time farmer

CROP DATA								
Seasons	Crop(s)	Cycle(s)	Average yield (kg/m²)	Crop lines orientation	Plants by m²	Are foliar analyses carried out?	Do you use alternative systems to phytosanitary products?	Do you use grafts?
2010/2011 to 2012/2013	Autumn: Eggplant Spring: Watermelon	2 short	Autumn: 7.0 Spring: 4.0	North - South	0,7 eggplant 0,5 watermelon	Yes, coop.	Colour traps	Yes (Watermelon)

SOIL DATA						
Soil type	Is soil disinfected?	Is broadcasting performed?	Surface and frequency	Type of fertilizer	Is soil analysed?	Do you add humic acids?
Sanded (2/3)	Yes, solarisation and disinfection every year	Yes	Banding / 2-3 years	Prepared sacks	Yes	Yes

IRRIGATION SYSTEM		
water of farm well (%)	Total average cost €/m³	Total average conductivity (dS/m)
0		0.8

MARKETING DATA								
Where is your product sold?	Are all of your products brought to the same location?	Are you a member of a cooperative?	How many years?	Do you receive technical advice?	Type of advice	Do you prepare the products yourself?	harvest time dedicated to preparing the products? (%)	Certification systems
Cooperative	Yes	Yes	> 10	Always	Cooperative	No		UNE-155.000, Global GAP and Integrated production

Table 43 (cont.). Profile of the holdings with the highest average production yield for two short-cycle crops of eggplant and watermelon by season

DATA ON THE GREENHOUSE STRUCTURE							
Age (years)	**Greenhouse type**	**Orientation**	**Surface (m^2)**	**Cover material**	**Type of support**	**Maximum height (ridge)**	**Minimum height (below channel)**
12	*Raspa y amagado*	North - South	5,500	Three-layer plastic	Metal tubes	4.7	4.3
Type of roof window	**windows per span (%)**	**surface with roof ventilation (%)**	**Type of side vents**	**Number of side vents**	**surface with side ventilation (%)**	**total ventilation (%)**	
Flap ventilators	100	7.6	Sliding bands	4	14.6	22.2	

CLIMATE CONTROL SYSTEM			
Do you use a climate controller?	**Do you have a forced ventilation system installed?**	**Do you have a water evaporative cooling system installed?**	**Heating system?**
No	No	Yes. fogging	No

LABOUR DATA		
Own or contracted?	**Relationship with the contracted personnel?**	**Use of contracted personnel**
Contracted	25 % temporary; 75 % permanent disc.	Collection

Table 44. Profile of the holdings with the highest average production yield for one long-cycle crop of eggplant by season

Locations	Bajo Andarax	Campo de Dalías	Campo de Níjar	Bajo Almanzora
Number	0	10	0	0

FARMER PROFILE				
Average age	**Experience**	**Land ownership**	**Level of studies**	**Dedication**
46	28	Owner	Primary studies	Full time farmer

CROP DATA								
Seasons	**Crop(s)**	**Cycle(s)**	**Average yield (kg/m²)**	**Crop lines orientation**	**Plants by m²**	**Are foliar analyses carried out?**	**Do you use alternative systems to phytosanitary products?**	**Do you use grafts?**
2010/2011 to 2012/2013	Eggplant in long cycle	Long	14.7	North - South (7/10)	0,6	Yes, coop. (5/10)	Colour traps; integrated control	Yes (eggplant) (3/10)

SOIL DATA						
Soil type	**Is soil disinfected?**	**Is broadcasting performed?**	**Surface and frequency**	**Type of fertilizer**	**Is soil analysed?**	**Do you add humic acids?**
Sanded (9/10) Hydroponic (1/10)	Yes, solarisation and disinfection every year	Yes (7/10)	Banding / 3-4 years	Sheep (4/10) Sacks (3/10)	Yes	Yes

IRRIGATION SYSTEM		
water of farm well (%)	**Total average cost €/m³**	**Total average conductivity (dS/m)**
0	0.2	0.7

MARKETING DATA								
Where is your product sold?	**Are all of your products brought to the same location?**	**Are you a member of a cooperative?**	**How many years?**	**Do you receive technical advice?**	**Type of advice**	**Do you prepare the products yourself?**	**harvest time dedicated to preparing the products? (%)**	**Certification systems**
Cooperative and SAT	Always	Yes	> 10	Always	Cooperative	No (8/10)		UNE-155.000, Naturane and integrated prod.

Table 44 (cont.). Profile of the holdings with the highest average production yield for one long-cycle crop of eggplant by season

DATA ON THE GREENHOUSE STRUCTURE

Age (years)	Greenhouse type	Orientation	Surface (m²)	Cover material	Type of support	Maximum height (ridge)	Minimum height (below channel)
15	*Raspa y amagado* (9/10) Flat roof (1/10)	North - South (9/10)	12,680	Three-layer plastic	Metal tubes	4.1 (*raspa*) 2.6 (Flat-roof)	3.5 (*raspa*) 2.6 (Flat-roof)

Type of roof window	windows per span (%)	surface with roof ventilation (%)	Type of side vents	Number of side vents	surface with side ventilation (%)	total ventilation (%)
Flap ventilators (6/10)	31.0	3.6	Sliding bands (10/10)	4	7.1 (*Raspa y amagado*)	10.7

CLIMATE CONTROL SYSTEM

Do you use a climate controller?	Do you have a forced ventilation system installed?	Do you have a water evaporative cooling system installed?	Heating system?
No	No	No	No

LABOUR DATA

Own or contracted?	Relationship with the contracted personnel?	Use of contracted personnel
Contracted (10/10)	23 % temporary; 65 % permanent disc.	Sowing and collection

6. Conclusions

A comprehensive analysis of the technological evolution of the greenhouse agriculture in the province of Almería over the past 16 years was performed. The yields of major crops in Almería were quantified according to the agricultural region and type of greenhouse used. In addition, the average profile of the ten best agricultural holdings with the highest estimated gross revenue was determined for each of the agricultural regions of Almería, and the average profiles of the top holdings with the highest production yields by season were determined according to the combination of crops and cycles used. Based on the above analysis, we can draw the following conclusions.

The combination of the Almería-type greenhouse with sand plots is still after 50 years in excellent condition since it is the most profitable alternative in most of the cases. The multi-span structure types gain more relevance only in long cycles, particularly for tomatoes. These structures are also noteworthy for certain specialty crops, such as cucumber, in which heating is sometimes used.

The greenhouses of Almería are energy efficient because they produce more kilograms of fruit and vegetables per unit of energy and have higher yields per square meter compared with regions that include more technologically advanced greenhouses. In addition, the average production in Almería is competitive compared to that of other regions in which greenhouses without advanced technology (especially climate control technology) are employed. The Almería Model is most likely the one that provides the best adaptation to the new requirements of European consumers, who demand high-quality products as well as the lowest possible environmental costs.

Crop management based on advanced technological implementations does not necessarily result in greater commercial productivity and a higher yield. This result confirms the interest of specialising in those crops and production systems that do render the investments profitable and the need to reduce production costs and follow a suitable production orientation.

Improvements to natural ventilation systems result in an increase in production without significant cost compared with other climate control systems. The ventilation capacity of the Almería-type greenhouse must be improved, since it is still currently insufficient despite the improvements in recent years. The average window surface in 2013 was 14.4 %, which is far from the minimum window surface value of 30 % that is required for correct ventilation or even the value of 25 %, which is recommended in the Regulation for Integrated Production.

Referencias bibiográficas

Abbes, K. y Chermiti, B. (2011): «Comparison of two marks of sex pheromone dispensers commercialized in Tunisia for their efficiency to monitor and to control by mass-trapping *Tuta absoluta* under Greenhouses»; *Tunisian Journal of Plant Protection*, 6(2); pp. 133-148.

Acebedo, M. M. (2004): «*Bemisisa tabaci*, una de las principales plagas en cultivos bajo abrigo»; *Vida Rural* (189); pp. 31-34.

Aguilar, B. (1981): *Diversos tipos de estructuras de los abrigos de la zona del Campo de Dalías (Almería)*. Comunicación a las Jornadas de los Estudios Internacionales de la Sección Técnica de la Comisión Internacional de Ingeniería Rural. Almería, febrero de 1981.

Aikman, D. P. (1996): «A procedure for optimizing carbon dioxide enrichment of a glasshouse tomato crop»; *Journal of Agricultural Engineering Research* (63); pp. 171-184.

Albadalejo, J. (1991): «Pantalla térmica. Microclima óptimo para sus plantas»; *Horticultura* (62); pp. 136-138.

Albadalejo, J. y Plaisier, H. (1991): «Tecnología de umbráculos con pantallas térmicas aluminizadas. Parte I»; *Horticultura* (67); pp. 70-76.

Albright, L. D. y Both, A. J. (1990): *Screening materials for thrips exclusion in greenhouses*. Proceedings of the Fifty-second annual Nueva York State Pest Management Conference. Cornell University. 12-15 de noviembre, Ithaca (EEUU); p. 7.

Al-Helal, M. S. (1998): *A computational fluid dynamics study of natural ventilation in arid region greenhouses*. Tesis Doctoral, Ohio State University, Ohio (EEUU); p. 186.

Álvarez, A. J. (2009): *Estudio de las características geométricas y del comportamiento aerodinámico de las mallas antiinsectos utilizadas en los invernaderos como medida de protección vegetal*. Tesis Doctoral, Departamento de Ingeniería Rural, Universidad de Almería, Almería (España); p. 423.

Álvarez, A. J.; Valera, D. L. y Molina-Aiz, F. D. (2003): *Importancia de la caracterización geométrica y del comportamiento aerodinámico de los agrotextiles utilizados en invernaderos*. I Congreso Andaluz de Ingenieros Agrónomos. 16, 17 y 18 de octubre, Sevilla. Comunicación 4c-2; p. 13.

Al-Shoshan, A.; Short T. H.; McMahon R. W. y Fynn R. P. (1991): *Evapotranspiration measurment and modeling of a greenhouse grown chrysanthemum crop*. ASAE paper No. 91-4043. ASAE, St. Joseph (EEUU).

Amsen, M. G. (1981): «Environmental conditions in different types of greenhouses»; *Acta Horticulturae* (115); pp. 99-104.

Annesi, T. A. y Motta, E. (1994): «Soil solarization in an Italian forest nursery»; *European Journal of Plant Pathology* (24); pp. 203-209.

Aparicio, V.; Belda, J. E.; Casado, E.; García, M.; Gómez, V.; Lastres, J.; Mirasol, E.; Roldan, E.; Sáez, E.; Sánchez, A. y Torres, M. (1998): *Plagas y enfermedades en cultivos hortícolas de la provincia de Almería: control racional*. Consejería de Agricultura y Pesca. Junta de Andalucía, Andalucía (España); p. 356.

Arbel, A.; Yekutieh, O. y Barak, M. (1999): «Performance of a fog system for cooling greenhouses»; *Journal of Agricultural Engineering Research* (72); pp. 129-36.

Arbel, A.; Barak, M. y Shklyar, A. (2003): «Combination of Forced Ventilation and Fogging Greenhouses»; *Biosystems Engineering*, 84 (1); pp. 45-55.

Arellano, M. A.; Valera, D. L.; Urrestarazu, M. y Molina-Aiz, F. D. (2002): *Characterisation of the microclimate in an Almería type greenhouse* paper nº 02-SE-058. International Conference on Agricultural Engineering EurAgEng 2002, 30 Junio-4 Julio 2004. Budapest, Hungría; p. 4.

Arellano, M. A.; Valera, D. L.; Molina-Aiz, F. D. y Urrestarazu, M. (2003): *Efecto del microclima originado en un invernadero Almería en el rendimiento y calidad de un cultivo de pepino*. Actas del 2º Congreso Nacional de Agroingeniería, Córdoba (España), AG03-0703; pp. 570-575.

Arellano, M. A. (2004): *Caracterización Microclimática del Invernadero Almería y Análisis de la Ventilación Forzada como Vía de Mejora de los Parámetros Ambientales que Optimicen la Producción y Calidad de Diversos Cultivos Hortícolas*. Tesis Doctoral. Universidad de Almería, Almería (España).

ASAE (American Society of Agricultural Engineers) (1981): «Heating, ventilating and cooling greenhouses»; *Agricultural Engineers Yearbook, ASAE Engineering Pratice* (406); pp. 401-404.

ASAE (1994): *Heating, Ventilating and Cooling Greenhouses. American Society of Agricultural Engineers*. St. Joseph (EEUU), ANSI-ASAE Standard. EP406.1; pp: 565-568.

ASAE (2003): *Heating, Ventilating and Cooling Greenhouses*. ANSI/ASAE EP406.4 JAN03. American Society of Agricultural Engineers. St. Joseph, Míchigan (EEUU).

ASHRAE (1972): *ASHRAE Handbook of Fundamentals*. Chapter 10. American Society of Heating, Refrigeration, and Air-Conditioning Engineers. New York (EEUU).

Aznar, J. A.; Galdeano, E.; Álvarez, J.; Tapia, J. J. y Godoy, A. (2013): *El sector de la comercialización hortícola en Almería*. Ed. Cajamar Caja Rural, Almería (España), p. 121.

Bailey, B. J. (1978): «Heat consevation in glasshouses with aluminised thermal screens»; *Acta Horticulturae* (76); pp. 275-278.

Bailey, B. J. (1980): «The evaluation of thermal screens in glasshouses on commercial nurseries»; *Acta Horticulturae* (115); pp. 663-670.

Bailey, B. J. (1985): «Microclimate, physical processes and greenhouse technology»; *Acta Horticulturae* (174); pp. 35-42.

Baille, M.; Laury, J. C. y Baille, A. (1984): «Influence d'un écran thermique sur le bilan énergétique et le microclimat nocturnes d'une serre»; *Agronomie*, 4(4); pp. 327-332.

Baille, A.; Aries, F.; Baille, M. y Laury, J. C. (1985): «Influence of thermal screen optical properties on heat losses and microclimate of greenhouses»; *Acta Horticulturae* (174); pp. 111-117.

Baille, A.; Kittas, C. y Katsoulas, N. (2001): «Influence of whitening on greenhouse microclimate and crop energy partitioning»; *Agricultural and Forest Meteorology* (107); pp. 293-306.

Baker, J. R. y Jones, R. K. (1989): «Screening as part of insect and disease management in the greenhouse»; *N.C. Flower Growers' Bull* (34); pp. 1-9.

Baker, J. R. y Jones, R. K. (1990): «An update on screening as part of insect and disease management in the greenhouse»; *N.C. Flower Growers' Bull* (35); pp. 1-3.

Balachowsky, A. S. (1951): *La Lutte contre les Insectes*. Ed. Payot, París (Francia); p. 380.

Barral, J. R.; Galimberti, P. D.; Barone, A. y Miguel A. L. (1999): «Integrated thermal improvements for greenhouse cultivation in the central part of Argentina»; *Solar Energy*, 67(1-3); pp. 111-118.

Barrett, R. E.; Ormrod, D. P. y Jung, R. (1978): «Soil heating effects on bench-grown Chrysanthemums»; *HortScience*, 13(5); pp. 591-592.

Bartzanas, Th.; Boulard, T. y Kittas, C. (2002): «Numerical simulation of the airflow and temperature distribution in a tunnel greenhouse equipped with insect-proof screen in the openings»; *Computers and Electronics in Agriculture* (34); pp. 207-221.

Bartzanas, T. y Kittas, C. (2004): *Heat and Mass Transfer in a Large Evaporative Cooled Greenhouse Equipped with a Progressive Shading*. GREENSYS 2004, 12-16 Septiembre, Leuven (Bélgica).

Bauerle, W. L. y Short, T. H. (1977): «Conserving heat in glass greenhouses with surface-mounted air-inflated plastic»; *Ohio Agricultural Research and Development Center*. Special circular 101.

Bauerle, W. L. y Short, T. H. (1981): «Changes in practices for energy conservative greenhouses»; *Acta Horticulturae* (115); pp. 309-310.

Baxter, D. O. (1994): «Energy exchanges and related temperatures of an earth-tube heat exchanger in the cooling mode»; *Transactions of the ASAE*, 37(1); pp. 257-267.

Bell, M. L. y Baker, J. R. (2000): «Comparison of greenhouse screening materials for excluding Whitefly (Homoptera: Aleyrodidae) and Thrips (Thysanoptera: Thripidae)»; *Journal of Economic Entomology* (93); pp. 800-804.

Bell, M. L. y Baker, J. R. (2001): «Greenhouse insect-screens making the right selection»; *The Nursery Papers* (1999-91); pp. 1-6.

Ben Yephet, Y.; Stapleton, J. J.; Wakeman, R. J. y DeVay, J. E. (1987): «Comparative effect of soil solarization with single and double layer of polyethylene film on survival of *Fusarium oxysporum* f. sp. *vasinfectum*»; *Phytoparasitica* (15); pp. 181-185.

Benassy, C. (1977): «Lucha biológica e integrada en la protección de plantas»; *Bol. Serv. Plagas* (3); pp. 75-86.

Berlinger, M. J.; Mordechl, S. y Leeper, A. (1991): «Application of screens to prevent whitefly penetration into greenhouses in the Mediterranean Basin»; proceedings of the Working Group Integrated Control in *Protecting Crops under Mediterranean Climate*, 29 de septiembre-2 de octubre, Alassio (Italia); pp. 105-110.

Berlinger, M. J.; Mordechl, S.; Fridja, D. y Mar, N. (1992): «The effect of types of greenhouse screens on the presence of western flower thrips: a preliminary study»; *Contribution from the Agricultural Research Organization* (3716-E); 1992 series. The Volcán Center, Bet Dagan (Israel); pp. 13-16.

Bethke, J. A. (1994): «Considering installing screening? This is what you need to know»; *Greenhouse Manager*, 13(1); pp. 34-37.

Bethke, J. A. y Paine, T. D. (1991): «Screen hole size and barriers for exclusion of insect pests of glasshouse crops»; *Journal of Entomological Science*, 26(1); pp. 169-177.

Bethke, J. A.; Redak, R. A. y Paine, T. D. (1994): «Screens deny specific pests entry to greenhouses»; *California Agriculture*, Mayo-Junio; pp. 37-40.

Bianchi, A. (1989): «Tipologie costruttive ed impiantistiche nelle colture protette»; *Colture Protette* (7); pp. 23-26.

Boesman, G.; Derouich, M. y Verlodt, H. (1984): «Influence of solar heating and thermal screen on the greenhouse climate and the yield of pepper (Capsicum annuum L.)»; *Acta Horticulturae* (154); pp. 267-279.

Bot, G. P. A. (1983): *Greenhouse climate: from physical processes to a dynamic model*. Tesis Doctoral. Agricultural University of Wageningen. Holanda; p. 240.

Both, A. J.; Albright, L. D. y Langhans, R. W. (1997): «Consideated management of daily PAR integratal and carbon dioxide for hydroponic lettuce production»; *Acta Horticulturae* (456); pp. 45-51.

Boulard, T. y Baille, A. (1993): «Simple greenhouse climate control incorporating effects of ventilation and evaporative cooling»; *Agricultural and Forest Meteorology* (65); pp. 3-4.

Boulard, T. y Draoui, B. (1995): «Natural ventilation of a greenhouse with continuous roof vents: measurements and data analysis»; *Journal of Agricultural Engineering Research* (61); pp. 27-36.

Boulard, T.; Feuilloley, P. y Kittas, C. (1997): «Natural ventilation performance of six greenhouse and tunnel types»; *Journal of Agricultural Engineering Research* (67); pp. 249-266.

Boulard, T.; Raeppel, C.; Brun, R.; Lecompte, F.; Hayer, F.; Carmassi, G. y Gaillard, G. (2011): «Environmental impact of greenhouse tomato production in France»; *Agronomy for Sustainable Development*, 31(4); pp. 757-777.

Brader, L. (1975): *Integrated control, a new approach in crop protection*. C. R. 5è Svmp. Lutte int. vergers OilblSrop, 9-1.

Bretones, F. (2003): «El enarenado»; en Camacho Ferre, F., coord.: *Técnicas de producción en cultivos protegidos* (1); Caja Rural Intermediterránea, Cajamar, Almería; pp. 109-118.

Briassoulis, D.; Waaijenberg, D.; Gratraud, J. y Von Eslner, B. (1997): «Mechanical properties of covering materials for greenhouses: part 1, general overview»; *Journal of Agricultural Engineering Research* (67); pp. 81-96.

Buffington, D. E.; Bucklin, R. A.; Henley, R. W. y McConnell, D. B. (1987): *Greenhouse ventilation*. Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida, Fact Sheet AE-10, Gainesville (EEUU); p. 5.

Businger, J. A. (1963): «The glasshouse (greenhouse) climate»; en van Wijk, ed.: *Physics of Plant Environment*. North-Holland Publishing Co., Amsterdam (Holanda); pp. 277-318.

Byrne, D. N.; Bretzel, P. K. V. y Hoffman, C. J. (1986): «Impact of trap design and placement when monitoring for the bandedwinged whitefly and the sweetpotato whitefly (Homoptera: Aleyrodidae)»; *Environmental Entomology* (15); pp. 300-304.

Calvert, A. y Slack, G. (1975): «Light-dependent control of day temperature for early tomato crops»; *Acta Horticulturae* (51); pp. 163-168.

Camacho-Ferre, F. (1980): «Cultivos intensivos en la provincia almeriense. Equipo de Ciencias Naturales 'Los Filabres1»; en *Serie Monografías*. Almería (España), p. 16.

Camacho, F. (2003): *Técnicas de Producción en Cultivos Protegidos*. Ed. Caja Rural Intermediterránea (Cajamar), Almería (España); p. 776.

Camacho, F. y Cortés, F. J. (2009): «La innovación, base del sostenimiento de la horticultura protegida de Almería»; *Distribución y consumo*; pp. 52-62.

Campen, J. B. (2003): «Greenhouse characteristics and climatic conditions using 3D computational fluid dynamics calculations»; *Acta Horticulturae* (614); pp. 347-351.

Campen, J. B. (2005): «Greenhouse design applying CFD for Indonesian conditions»; *Acta Horticulturae* (691); pp. 419-424.

Campen, J. B. y Bot, G. P. A. (2003): «Determination of greenhouse-specific aspect of ventilation using three-dimensional computational fluid dynamics»; *Biosystems Engineering*, 84(1); pp. 69-77.

Campra, P.; García, M.; Canton, Y. y Palacios-Orueta, A. (2008): «Surface temperature cooling trends and negative radiative forcing due to land use change toward greenhouse farming in southeastern Spain»; *Journal of Geophysical Research* (113); D18109.

Campra, P. y Millstein, D. (2013): «Mesoscale climatic simulation of surface air temperature cooling by highly reflective greenhouses in SE Spain»; *Environmental Science & Technology*, 47(21); pp. 12284-12290.

Camprubi, A.; Estaùn, V.; El Bakali M. A.; Garcia-Figueres, F. y Calvet, C. (2007): «Alternative strawberry production using solarization, metham sodium, and beneficial soil microbes as plant protection methods»; *Agronomy for Sustainable Development*, 27(3); pp. 179-184.

CAPMA (2012): «Fichas de productos. Campaña 2011/12»; *Sector hortícolas protegidos*. Observatorio de precios y mercados. Consejería de Agricultura Pesca y Medio Ambiente. Junta de Andalucía, Andalucía (España).

CAPMA (2013a): *Cartografía de invernaderos en el litoral de Andalucía Oriental. Campaña 2012*. Consejería de Agricultura Pesca y Medio Ambiente. Junta de Andalucía, Andalucía (España), p. 21.

CAPMA (2013b): «Boletín Final»; *Avance valoración de campaña 2012/13 hortalizas protegidas*. Almería. Observatorio de precios y mercados. Junta de Andalucía, Andalucía (España).

Carlsson-Kanyama, A. (1998): «Climate change and dietary choices-how can emissions of greenhouse gases from food consumption be reduced?»; *Food Policy*, 23(3-4); pp. 277-293.

Castilla, N.; Gimenez, C. y Fereres, E. (1986): «Tomato root development on sand mulch, plastic greenhouse in Almería (Spain)»; *Acta Horticulturae* (191); pp. 113-122.

Castilla, N. (1994): «Greenhouse in the mediterranean area: technological level and strategic management»; *Acta Horticulturae* (361); pp. 44-56.

Castilla, N. (2001): «La radiación solar en invernadero en la costa mediterránea española»; en Cajamar, ed.; *Incorporación de tecnología al invernadero mediterráneo*. El Ejido, Almería (España); pp: 36-47.

Castilla, N. (2005): *Invernaderos de plástico. Tecnología y manejo*. Ed. Mundi-Prensa, Madrid (España), p. 462.

Castilla, N. y Hernadez, J. (1995): «Protected cultivation in the Mediterranean area»; *Plasticulture*, 107(3); pp. 13-20.

Cellura, M.; Longo S. y Mistretta M. (2012): «Life Cycle Assessment (LCA) of protected crops: an Italian case study»; *Journal of Cleaner Production* (28); pp. 56-62.

CEPLA (1992): «Actas del XII Congreso Internacional de Plásticos en Agricultura 3-8 Mayo 1992». Granada (España).

Chalabi, Z. S. y Critten, D. L. (1990): «The influence of real time filtering strategies on optimal CO_2 concentration for a greenhouse lettuce crop»; *Acta Horticulturae* (268); 139-148.

Chavarría-Carvajal, J. A.; Rodríguez-Kabana, R.; Kloepper, J. W. y Morgan Jones, G. (2001): «Changes in populations of microorganisms associated with organic amendments and benzaldehyde to control plant-parasitic nematodes»; *Nematropica* (31); pp. 165-180.

Chen, Y.; Gamliel, A.; Stapleton J. J. y Aviad, T. (1991): «Chemical, physical, and microbial changes related to plant growth in disinfested soils»; in Katan, J.; DeVay, J. E., eds.: *Soil Solarization*. CRC Press, Boca Raton; pp. 103-129.

Christensen, L. K. y Thinggaard, K. (1999): «Solarization of greenhouse soil for prevention of Pythium root rot in organically grown cucumber»; *Journal of Plant Pathology* (81); pp. 137-144.

COEXPHAL (2013): «La Asamblea General de COEXPHAL hace balance de la pasada campaña y analiza las acciones desarrolladas durante la misma»; nota de prensa de la Asociación de Organizaciones de Productores de Frutas y Hortalizas de Almería de 11 de octubre de 2013, Almería (España).

D'Emilio, A.; Mazzarella, R.; Porto, S. M. C. y Cascone, G. (2012): «Neural networks for predicting greenhouse thermal regimes during Soil Solarization»; *Transactions of the ASABE*, 55(3); pp. 1093-1103.

Davis, P. F. y Hooper, A. W. (1991): «Improvement of greenhouse heating control»; *Proc. Institution of Electrical Engineers*, Part D, 138(3); pp. 249-255.

de Graaf, R. (1985): «The influence of thermal screening and moisture gap on the transpiration of glasshouse tomatoes during the night»; *Acta Horticulturae* (174); pp. 57-66.

de Halleux, D. y Gauthier, L. (1998): «Energy consumption due to dehumidification of greenhouses under northern latitudes»; *Journal of Agricultural Engineering Research* (69); pp. 35-42.

Deltour, J.; de Halleux, D.; Nijskens, J.; Coutisse, S. y Nisen, A. (1985): «Dynamic modelling of heat and mass transfer in greenhouses»; *Acta Horticulturae* (174); pp. 119-126.

Desneux, N.; Wajnberg, E.; Wyckhuys, K. A. G.; Burgio, G.; Arpaia, S.; Narváez-Vasquez, C. A.; González-Cabrera, J.; Catalán, D.; Tabone, E.; Frandon, J.; Pizzol, J.; Poncet, C.; Cabello, T. y Urbaneja, A. (2010): «Biological invasion of European tomato crops by *Tuta absoluta*: ecology, geographic expansion and prospects for biological control»; *Journal of Pest Science* (83); pp. 197-215.

Díaz, M.; Carmona, J. J.; Fernández, E. J.; Gallardo, D. y Camacho, F. (2003): «Utilización de mallas anti-insectos como protección en invernaderos mediterráneos. Efectos de la densidad de hilos y de la fotoselectividad sobre la difusión del TYLCV (Virus de la cuchara) en el cultivo de tomate»; en Fernández, E.J., ed.: *Innovaciones tecnológicas en cultivos de invernadero*. Ediciones Agrotécnicas SL. Madrid (España); pp. 165-175.

Dierickx, W. (1998): «Flow reduction of synthetic screens obtained with both a water and airflow apparatus»; *Journal of Agricultural Engineering Research* (71); pp. 67-73.

Doble, S. J.; Matthews, G. A.; Rutherford, I. y Southcombe, E. S. E. (1985): «A system for classifying hydraulic nozzles and other atomisers into categories of spray quality»; *Proceedings of the British Crop Protection Conference-Weeds* (3); pp. 1125-1133.

Duff, J. D. y Connelly, M. I. (1993): «Effect of solarization using single and double layers of clear plastic mulch in *Pythium, Phytophthora* and *Sclerotium* species in a nursery potting mix»; *Australasian Plant Pathology* (22); pp. 28-35.

Duncan, G. A.; Loewer, Jr. O. J. y Colliver, D. G. (1981): «Simulation of energy flows in a greenhouse: magnitudes and conservation potential»; *Transactions of the ASAE*, 24(4); pp. 1014-1021.

Enoch, H. Z. (1984): «Carbon dioxide uptake efficiency in relation to crop intercepted solar radiation»; *Acta Horticulturae* (162); pp. 137-147.

Eguaras, J. (1988): *Ibn Luyun: tratado de agricultura*. Patronato de la Alhambra y Generalife, Granada, 302 pp.

FAO (Food and Agriculture Organization of the United Nations) (2002): «El cultivo protegido en clima mediterráneo»; *Estudio FAO Producción y Protección Vegetal* (90). Organización de las Naciones Unidas para la Agricultura y la Alimentación, Roma (Italia); p. 320.

Fatnassi, H.; Boulard, T. y Bouirden, L. (2002a): «Simulation of air flux and temperature patterns in a large scale greenhouse equipped with insect proof nets»; *Acta Horticulturae* (578); pp. 329-338.

Fatnassi, H.; Boulard, T.; Demrati, H.; Bouirden, L. y Sappe, G. (2002b): «Ventilation performance of a large Canarian type greenhouse equipe with insect-proof nets»; *Biosystems Engineering*, 82(1); pp. 97-105.

Fatnassi, H.; Boulard, T.; Poncet, C. y Chave, M. (2006): «Optimisation of greenhouse insect screening with computational fluid dynamics»; *Biosystems Engineering*, 93(3); pp. 301-312.

Fatnassi, H.; Leyronas, C.; Boulard, T.; Bardin, M. y Nicot, P. (2009): «Dependence of greenhouse tunnel ventilation on wind direction and crop height»; *Biosystems engineering* (103); pp. 338-343.

Ferare, J. y Goldsberry, K. L. (1984): «Environmental conditions created by plastic greenhouse covers»; *Acta Horticulturae* (148); pp. 675-682.

Ferentinos, K. P.; Albright, L. D. y Ramani, D. V. (2000): «Optimal light integral and carbon dioxide concentration combinations for lettuce in ventilated greenhouses»; *Journal of Agricultural Engineering Research*, 77(3); pp. 309-315.

Ferguson, J. H. A. (1960): «A comparison of two planting systems in orchards as regards the amount of radiation intercepted by the trees»; *Netherlands Journal of Agricultural Science* (8); pp. 271-280.

Fernández, O. y Pizarro, A. (1981): «Almeria: la tecnica del 'enarenado' transforma un desierto»; *Revista de Estudios Agrosociales* (115); pp. 31-70.

Fernández, J. E. y Bailey, B. J. (1993): «Predicting greenhouse ventilation rates»; *Acta Horticulturae* (328); pp. 107-114.

Fernández, C. y Pérez-Parra, J. J. (2004): *Caracterización de los invernaderos de la provincia de Almería*. Cajamar, El Ejido (Almería); p. 20.

Fernández, E. J.; Camacho, F.; Díaz, M. y Martínez, E. J. (2002a): «Efectos de la utilización de mallas de 20x10 hilos/cm (50 mesh) sobre los niveles de poblaciones de mosca blanca y trips bajo invernadero en cultivo de tomate y sobre la incidencia de TYLCV en el sureste español»; *Phytoma* (135); pp. 206-207.

Fernández, E. J.; Camacho, F. y Díaz, M. (2002b): «Influencia de la utilización de mallas 20x10 hilos/cm (50 mesh) fotoselectivas y no fotoselectivas sobre la incidencia del TYLCV en invernaderos mediterráneos del sureste español: primer avance»; *Phytoma* (135); pp. 210-211.

Ferrández-Villena, M.; Rocamora, M. C.; Puerto, H. M.; García, T.; Andreu, J.; Ruiz, A.; Cámara, J. M.; Melián, A. y Abadía, R. (2002): «Study of the head losses along the nozzles conduct of a fog-forming system with venturi effect for the control of temperature in a greenhouse»; *EurAgEng 2002*, Budapest (Hungría): 02-SE-050.

Feuilloley, P.; Guillaume, S. y Issanchou, G. (1989): «Couverture de serre. Mesure de la transparence thermique des matériaux»; *CEMAGREF, BTMEA* (35); janvier 1989; pp. 24-32.

Feuilloley, P.; Issanchou, G.; Jacques, J. C.; Guillaume, S.; Mekikdjian, Ch.; Mirabella, J. F. y Merlot, A. (1994a): «Films plastique de couverture de serre: condensations et propriétés thermiques. Résultats de mesure»; *Plasticulture* (103); pp. 2-10.

Feuilloley, P.; Mekikdjian, Ch. y Lagier, J. (1994b): «Aeration naturelle des serres-tunnels plastique en zone méditerranéenne»; *Plasticulture* (104); pp. 33-46.

Feuilloley, P. y Issanchou, G. (1996): «Greenhouse covering materials measurement and modelling of thermal properties using the hot box method and condensation effects»; *Journal of Agricultural Engineering Research* (65); pp. 129-142.

Fierro, A.; Tremblay, N. y Gosselin, A. (1994): «Supplemental carbon dioxide and light improved tomato and pepper seedling growth and yield»; *HortScience*, 29(3); pp. 152-154.

Filho, M. M.; Vilela, E. F.; Attygalle, A. B.; Meinwald, J.; Svatoš, A. y Jham, G. N. (2000): «Field trapping of tomato moth, *Tuta absoluta* with pheromone traps»; *Journal of Chemical Ecology*, 26(4); pp. 875-881.

French-Monar, R. D.; Jones, J. B.; Ozores-Hampton, M. y Roberts, P. D. (2007): «Survival of inoculum of *Phytophthora capsici* in soil through time under different soil treatments»; *Plant Disease*, 91(5); pp. 593-598.

Frenkel, H. (1986): «Pesticide application, technique and eficiency»; en Palti, J. y Ausher, R., ed.: *Advisory Work in Crop Pest and Disease Management*, Springer, Nueva York (EEUU); pp. 132-160.

Fuchs, M.; Dayan, E.; Shmuel, D. y Zipori, I. (1997): «Effects of ventilation on the energy balance of a greenhouse with bare soil»; *Agricultural and Forest Meteorology* (86); pp. 273-282.

Fuller, R. J.; Meyer, C. P. y Sale, P. J. M. (1987): «Validation of a dynamic model for predicting energy use in greenhouses»; *Journal of Agricultural Engineering Research* (38); pp. 1-14.

Fundación Cajamar (2012): *Análisis de la campaña hortofrutícola de Almería Campaña 2011/2012*; ed. Fundación Cajamar, Almería (España), p. 90.

Gamliel, A.; Austerweil, M. y Kritzman, G. (2000): «Non-chemical approach to soil-borne pest management organic amendments»; *Crop Protection* (19); pp. 847-853.

García, J. L.; Plaza, S.; Durán, J. M.; Navas, L. M.; Benavente, R. M. y Luna, L. (1997): *Calefacción por suelo radiante. Horticultura* (124); pp. 105-108.

Gardner, P. (1984): «Energy Management Systems in Buildings»; *Energy Publications*; Newmarket (Inglaterra).

Garibaldi, A. y Tamietti, G. (1983): «Attempts to use soil solarization in closed glasshouses in northern Italy»; *Acta Horticulturae* (152); pp. 237-243.

Garzoli, K. V. (1989): «Energy efficient greenhouses»; *Acta Horticulturae* (245); pp. 53-62.

Ghidiu, G. M. y Roberts, W. J. (2003): *Greenhouse screening for insect control*; The State University of New Jersey, Rutgers Cooperative Extension, New Jersey (EEUU), FS640. p. 2.

Ghosal, M. K. y Tiwari, G. N. (2004): «Mathematical modeling for greenhouse heating by using thermal curtain and geothermal energy»; *Solar Energy* (76); pp. 603-613.

Giacomelli, G. A. y Ting, K. C. (1999): «Horticultural and engineering considerations for the design of integrated greenhouse plant production systems»; *Acta Horticulturae* (481); pp. 475-481.

Giacomelli, G. A. (2002): *Considerations for energy management of greenhouse heating and cooling*; Southern Greenhouse Vegetable Growers Association Conference. 19-20 Julio, Shreveport (EEUU); p. 10.

Giannakou, I. O.; Sidiropoulos, A. y Prophetou-Athanasiadou, D. (2002): «Chemical alternatives to methyl bromide for the control of root-knot nematodes in greenhouses»; *Pest Management Science* (58); pp. 290-296.

Gillespie, D. R. y Quirino, D. J. M. (1992); «Flight behaviour of the greenhouse whitefly, *Trialeurodes vaporariorum* (Westwood) (Homoptera: Aleurodidac), in relation to yellow sticky traps»; *The Canadian Entomologist* (124); pp. 907-916.

González Benavente-García, A. y Martinez García, P. F. (1981): «Improvement of the thermal environment of the propagation house and its effect on the tomato fruit-set»; *Acta Horticulturae* (115); pp. 301-307.

Guirao, P.; Beitia, F. y Cenis, J. L. (1997): «Biotype determination of Spanish populations of *Bemisia tabaci* (Hemiptera: Aleyrodidae)»; *Bulletin of Entomological Research* (87); pp. 587-593.

Gullino, M. L.; Minuto, A. y Garibaldi, A. (1998): «Improved method of bench solarization for the control of soil-borne diseases in basil»; *Crop Protection* (17); pp. 497-501.

Gutierrez Montes, J. L.; Adrados Blaise-Ombrecht, C.; Garcia Mari, E. y Cruz Gonzalez, J. M. (1992): «Suelo caliente e infrarrojos como calefacción»; *Horticultura* (76); pp. 46-53.

Hand, D. W. (1984): «Crop reponses to winter and summer CO_2 enrichment»; *Acta Horticulturae* (162); pp. 45-61.

Hand, D. W. y Hannah, M. A. (1978): «Sweet pepper: application of lower-than-normal temperatures for varying durations within the night period»; en *Repor Glasshouse Crops Research.* Institute Littlehampton (Reino Unido); pp. 53-55.

Heij, G. y Schapendonk, A. H. C. M. (1984): «CO_2 depletion in greenhouses»; *Acta Horticulturae* (148); pp. 351-355.

Heinz, K. M.; Parrella, M. P. y Newman, J. P. (1992): «Time-efficient use of yellow sticky traps in monitoring insect populations»; *Journal of Economic Entomology* (85); pp. 2263-2269.

Hellickson, M. A. y Walker, J. N. (1983): «Ventilation of Agricultural Structures»; *ASAE Monograph* (6). American Society of Agricultural Engineers (ASAE), St Joseph (EEUU), p. 374.

Hendricks, P. (2012): «Life Cycle Assessment of greenhouse tomato (*Solanum lycopersicum* L.) production in southwestern Ontario». Tesis, University of Guelph, Ontario (Canadá), p. 95.

Hoitink, H. A. J. y Fahy, P. C. (1988): «Basis for the control of soil-borne plant pathogens with compost»; *Annual Review of Phytopathology* (24); pp. 93-114.

Horiuchi, S. (1991): «Solarization for greenhouse crops in Japan»; en DeVay, J. E.; Stapleton, J. J. y Elmore, C. L., eds.: *Soil Solarization. Plant Production and Protection;* paper 109. FAO, Roma; pp. 16-27.

Horticultural Statistics (1994): LEI-DLO and CBS. S-Gavenhage (Holanda).

Hurd, R. G. y Graves, C. J. (1984): «The influence of different temperature patterns having the same integral on tre earliness and yield of tomatoes»; *Acta Horticulturae* (148); pp. 547-554.

Huylenbroeck van, J. M. y Debergh, P. C. (1993): «Year-round production of flowering Calathea crocata: influence of light and carbon dioxide»; *HortScience*, 28(9); pp. 897-898.

Huys, J. F. G. y Mulder, W. P. (1981): «Economic aspect of heat pumps in glasshouse horticulture»; *Acta Horticulturae* (115); pp. 511-515.

Ioslovich, I.; Seginer, I.; Gutman, P. O. y Borshchevsky, M. (1995): «Sub-optimal CO_2 enrichment of greenhouses»; *Journal of Agricultural Engineering Research* (60); pp. 117-136.

Jackson, J. E. (1980): «Theory of light interception by orchards and a modelling approach to optimizing orchard design»; *Acta Horticulturae* (114); pp. 69-79.

Jackson, J. E. y Palmer, J. W. (1972): «Interception of light by model hedgerow orchards in relation to latitude, time of year and hedgerow configuration and orientation»; *Journal of Applied Ecology* (9); pp. 341-357.

Jaffrin, A. y Urban, L. (1990): «Optimization of light transmission in modern greenhouses»; *Acta Horticulturae* (281); pp. 25-33.

Janes, H. W. y McAvoy, R. (1983): «Deleterious effects of cool air temperature reversed by root-zone warming in poinsettia»; *HortScience*, 18(3); pp. 363-364.

Jayaraj, J. y Radhakrishnan, N. V. (2008): «Enhanced activity of introduced biocontrol agents in solarized soils and its implications of the integrated control of tomato damping-off caused by Pytium spp»; *Plant and Soil*, 304(1-2); pp. 189-197.

Junta de Andalucía (2006): *Caracterización de la deuda del sector hortícola de Almería 2005/06*. Consejería de Agricultura y Pesca, Secretaría General de Agricultura y Ganadería, Delegación Provincial de Almería, Almería, p. 34.

Junta de Andalucía (2010): *Anuario de estadísticas agrarias y pesqueras de Andalucía*. Ed. Consejería de Agricultura, Pesca y Desarrollo Rural, Andalucía (España).

Kacira, M.; Sase, S. y Okushima, L. (2004): «Review: Effects of side vents and span numbers on wind-induced natural ventilation of a gothic multi-span greenhouse»; *Japan Agricultural Research Quarterly*, 38(4); pp. 227-233.

Kacira, M.; Sase, S. y Okushima, L. (2004b): «Optimization of vent configuration by evaluating greenhouse and plant canopy ventilation rates under wind-induced ventilation»; *Transactions of the ASAE*, 47(6); pp. 2059–2067.

Katan, J.; Greenberger, A.; Alon, H. y Grinstein, A. (1976): «Solar heating by polyethylene mulching for the control of diseases caused by soilborne pathogens»; *Phytopahology* (66); pp. 683-688.

Katan, J.; Grinstein, A.; Greenberger, A.; Yarden, O. y Devay, J. E. (1987): «The first decade (1976-1986) of soil solarization (solar heating): A cronological bibliography»; *Phytoparasitica* (15); pp. 229-255.

Kempkes, F. L. K. y Van de Braak, N. J. (2000): «Heating system position and vertical microclimate distribution in chrysanthemum greenhouse»; *Agricultural and Forest Meteorology* (104); pp. 133-142.

Kittas, C.; Bartzanas, T. y Jaffrin, A. (2003): «Temperature gradients in a partially shaded large greenhouse equipped with evaporative cooling pads»; *Biosystems Engineering*, 85(1); pp. 87-94.

Kittas, C.; Boulard, T.; Mermier, M. y Papadakis, G. (1996): «Wind induced air exchange rates in a greenhouse tunnel with continuous side openings»; *Journal of Agricultural Engineering Research* (65); pp. 37-49.

Kittas, C.; Boulard, T. y Papadakis, G. (1997a): «Natural ventilation of a greenhouse with ridge and side openings: sensitivity to temperature and wind effects»; *Transactions of the ASAE*, 40(2); pp. 415-425.

Kittas, C.; Katsoulas, N.; Bartzanas, T.; Booulard, T. y Mermier, M. (2005): *Effect of vents' opening and insect screen on greenhouse ventilation*. International Conference Passive and low energy cooling for the built environment. Mayo 2005, Santoini (Grecia); pp. 59-64.

Kittas, C.; Katsoulas, N.; Bartzanas, T.; Boulard, T. y Mermier, M. (2006): «Effect of vent opening and insect screens on greenhouse microclimate distribution»; *Acta Horticulturae* (719); pp. 615-622.

Kittas, C.; Katsoulas, N.; Bartzanas, T.; Mermier, M. y Boulard, T. (2008): «The impact of insect screens and ventilation openings on the greenhouse microclimate»; *Transactions of the ASABE*, 51(6); pp. 2151-2165.

Kosmos, S. R.; Riskowski, G. L. y Christianson, L. L. (1993): «Force and static pressure resulting from airflow through screens»; *Transactions of ASAE* (36); pp. 1467-1472.

Lacasa, C. M.; Guerrero, M. M.; Ros, C.; Martínez, V.; Lacasa, A.; Fernández, P.; Núñez-Zofío, M.; Larregla, S.; Martínez, M. A.; Díez-Rojo, M. A. y Bello, A. (2010): «Efficacy of biosolarization with sugar beet vinasses for soil disinfestation in pepper greenhouses»; *Acta Horticulturae* (883); pp. 345-352.

La Malfa, G.; Noto, G.; Parrini, F. y Pulvirenti, S. (1993): «Riscaldamento di serre con reflui termici per la produzione di piante ornamentali»; *Colture Protette* (1); pp. 73-80.

Lamont, W. J. (1993): «Plastic mulches for the production of vegetable crops»; *HortTechnology*, 3(1); pp. 35-39.

Langhans, R. W.; Wolfe, M. y Albright, L. D. (1982): «Use of average night temperatures for plant growth for potential energy savings»; *Acta Horticulturae* (115); pp. 31-37.

Li, S.; Murata, K. y Takakura, T. (2000): «Direct solar radiation penetration into row crop canopies in a lean-to greenhouse»; *Agricultural and Forest Meteorology* (100); pp. 243-253.

Liao, Z. y Dexter, A. L. (2004): «The potential for energy saving in heating systems through improving boiler controls»; *Energy and Buildings* (36); pp. 261-271.

López, J. C.; Lorenzo, P.; Medrano, E.; Sánchez-Guerrero, M. C.; Pérez, J.; Puerto, H. M. y Arco, M. (2000): *Calefacción de invernaderos en el Sudeste Español*. Ed. Caja Rural de Almería; p. 54.

López, A.; Valera, D. L.; Molina-Aiz, F. D. y Peña, A. A. (2010): «Experimental evaluation by sonic anemometry of airflow in a Mediterranean greenhouse equipped with a pad-fan cooling system»; *Transactions of the ASAE*, 53(3); pp. 945-957.

López, A. (2011): *Contribución al conocimiento del microclima de los invernaderos mediante anemometría sónica y termografía*. Tesis Doctoral, Departamento de Ingeniería Rural, Universidad de Almería, Almería (España); p. 559.

López, A.; Valera, D. L.; Molina-Aiz, F. D. y Peña, A. A. (2012a): «Pad-fan systems in mediterranean greenhouses: determining optimal setup by sonic anemometry»; *Transaction of the ASABE*, 55(3); pp. 1077-1089.

López, A.; Valera, D. L.; Molina-Aiz, F. D. y Peña, A. A. (2012b): «Sonic anemometry to evaluate airflow characteristics and temperature distribution in empty Mediterranean greenhouses equipped with pad-fan and fog systems»; *Biosystems Engineering*, 113(4); pp. 334-350.

López, A.; Molina-Aiz, F. D.; Valera, D. L. y Peña, A. A. (2012c): «Determining the emissivity of the leaves of nine horticultural crops by means of infrared thermography»; *Scientia Horticulturae*, 137(1); pp. 49-58.

López, A.; Valera, D. L.; Molina-Aiz, F. D. y Peña, A. A. (2012d): «Air patterns in a Mediterranean greenhouse equipped with a cooling system»; *Acta Horticulturae* (927); pp. 651-658.

López, A.; Valera, D. L.; Molina-Aiz, F. D. y Peña, A. A. (2012f): «Thermography and sonic anemometry to analyze air heaters in Mediterranean greenhouses»; *Sensors* (12); pp. 12852-13870.

Mahrer, Y.; Avissar, R.; Naot, O. y Katan, J. (1987): «Intensified soil solarization with closed greenhouse: numerical and experimental studies»; *Agricultural and forest meteorology* (41); pp. 325-334.

Majdoubi, H.; Boulard, T.; Hanafi, A.; Bekkaoui, A.; Fatnassi, H.; Demrati, H.; Nya, M. y Bouirden, L. (2007): «Natural ventilation performance of a large greenhouse equipped with insect screens»; *Transactions of the ASABE*, 50(2); pp. 641–650.

Marín, J. (2013): *Portagrano 2013-2014: Vademécum de Variedades Hortícolas* (13ª edición). Ed. Portagrano, El Ejido, Almería (España), p. 439.

Martínez, M. A.; Martínez, M. C.; Bielza, P.; Tello, J. y Lacasa, A. (2011): «Effect of biofumigation with manure amendments and repeated biosolarization on *Fusarium* densities in pepper crops»; *Journal of Industrial Microbiology & Biotechnology*, 38(1); pp. 3-11.

McAvoy, R. J. (1992): «In situ plant canopy and potting medium temperatures under two greenhouse temperature regimes»; *HortScience*, 27(8); pp. 918-920.

Mears, D. R. y Both, A. J. (2000): *Insect exclusión from greenhouses*. Proceedings of the 15th Workshop on Agricultural Structures, and ACESYS (Automation, Culture, Environment and Systems) IV Conference. 4-5 de Diciembre, Tsukuba (Japón); pp. 18-26.

Mendizabal, M. y Verdejo, G. (1959): «Conservation de l'humidité et utilisation des sols salins par la culture sous sable ('arenado')»; *Symposium on Plant-Water Relationships in Arid and Semi-arid Conditions*, Madrid, 24-30 de septiembre de 1959; p. 5.

Meneses, J. F. y Monteiro, A. A. (1990): «Ducted air heating systems in greenhouses: experimental results. International Symposium on Simple Ventilation and Heating Methods for Greenhouses in Mild Winter Climates»; *Acta Horticulturae* (263); pp. 285-292.

Meneses, J. F. y Monteiro, A. A. (1993): «Greenhouses and protected crops in Portugal, some constraints and problems»; *Proceedings of Workshop on Environmentally Sound Water Management of Protected Agriculture under Mediterranean and Arid Climates*. Valenzano (Italia), 16-18 Julio; p. 609.

Miguel, A. F. (1998a): *Transport phenomena through porous screens and openings: from theory to greenhouse practice*. Tesis Doctoral. Agricultural University of Wageningen (Holanda), p. 239.

Miguel, A. F. (1998b): «Airflow through porous screens: from theory to practical considerations»; *Energy and Building* (28); pp. 63-69.

Miguel, A. F.; Van de Braak, N. J. y Bot, G. P. A. (1997): «Analysis of the airflow characteristics of greenhouse screening materials»; *Journal of Agricultural Engineering Research* (67); pp. 105-112.

Ministerio de Agricultura, Alimentación y Medio Ambiente (MAGRAMA) (2012): *Encuesta de Superficies y Rendimientos de Cultivos (ESYRCE)*, Resultados 2012. Ed Secretaría General Técnica Subdirección General de Estadística, Madrid (España); p. 166.

Ministerio de la Presidencia (2007): Reglamento de Instalaciones Térmicas en los Edificios (RITE). REAL DECRETO 1027/2007, de 20 de julio. BOE núm. 207 de Miércoles 29 agosto 2007: 35931-35984.

Minuto, A.; Spadaio, D.; Garibaldi, A. y Gullino, M. L. (2006): «Control of soil-borne pathogens of tomato using a commercial formulation of *Streptomyces griseoviridis* and solarization»; *Crop Prot.*, 25(5); pp. 468-475.

Mistriosis, A.; Bot, G. P. A.; Picuno, P. y Scarascia-Mugnozza, G. (1997): «Analysis of the efficiency of greenhouse ventilation using computational fluid dynamics»; *Agricultural and Forest Meteorology* (85); pp. 217-228.

Mistriotis, A.; Arcidiacono, C.; Picuno, P.; Bot, G. P. A. y Scarascia-Mugnozza, G. (1997b): «Computational analysis of ventilation in greenhouses at zero- and low-wind-speeds»; *Agricultural and Forest Meteorology* (88); pp. 121-135.

Molina-Aiz, F. D. (1997): *Identificación y valoración de los distintos tipos de invernaderos de la provincia de Almería para el análisis y control de sus condiciones ambientales*. Trabajo profesional fin de carrera. E.T.S.I.A.M. Córdoba (España); p. 229.

Molina-Aiz, F.D. (2010): *Simulación y modelación de la ventilación en invernaderos de Almería mediante la utilización de dinámica de fluidos computacional*. Tesis Doctoral, Universidad de Almería, Almería (España); p. 868.

Molina-Aiz, F.D.; Valera, D. L.; Álvarez, A. y Arellano, M. A. (2003): «Análisis y optimización de la ventilación de invernaderos mediante dinámica de fluidos computacional»; I Congreso Andaluz de Ingenieros Agrónomos. 16, 17 y 18 de octubre, Sevilla (España). *Comunicación,* 4c(1); p. 23.

Molina-Aiz, F. D.; Valera, D. L. y Álvarez, A. J. (2004a): «Using Computational Fluid Dynamics tool to model the internal climate of an Almería-type greenhouse»; *Acta Horticulturae* (654); pp. 271-278.

Molina-Aiz, F. D.; Valera, D. L. y Álvarez, A. J. (2004b): «Measurement and simulation of climate inside Almería-type greenhouses using Computational Fluid Dynamics»; *Agricultural and Forest Meteorology* (125); pp. 33-51.

Montero, J. I.; Antón, A.; Kamaruddin, R. y Bailey, B. J. (2001): «Analysis of thermally driven ventilation in tunnel greenhouses using small scale models»; *Journal of Agricultural Engineering Research*, 79(2); pp. 213-222.

Montero, J. I. (1994): «Instalaciones y métodos de control climático: calefacción»; en *Tecnología de invernaderos*. Curso superior de especialización. Dirección General de Investigación Agraria de la Junta de Andalucía y Fundación para la Investigación Agraria en la Provincia de Almería (FIAPA), Almería (España); pp. 201-217.

Montero, J. I.; Antón, A. y Biel, C. (1992): «Refrigeración de invernaderos II. Ventilación natural»; *Hortofruticultura* (6); pp. 69-71.

Montero, J. I.; Muñoz, P. y Anton, A. (1997): «Discharge coefficients of greenhouse windows with insect-proof screens»; *Acta Horticulturae* (443); pp. 71-77.

Montero, J. I.; Short, T. H.; Curry, R. B. y Bauerle, W. L. (1981): «Influence of evaporative cooling systems on greenhouse environment»; *ASAE* paper No. 81-4027. ASAE, St. Josepp (EEUU).

Moreau, T. L. y Isman, M. B. (2012): «Combining reduced-risk products, trap crops and yellow sticky traps for greenhouse whitefly (*Trialeurodes vaporariorum*) management on sweet peppers (*Capsicum annum*)»; *Crop Protection* (34); pp. 42-46.

Moriones, E.; Arnó, J.; Accotto, G. P.; Noris, E. y Cavallarin, L. (1993): «First report of tomato yellow leaf curl virus in Spain»; *Plant Disease* (77); p. 953.

Moss, G. I. (1983): «Root-zone warming of greenhouse tomatoes in nutrient film as a means of reducing heating requirements»; *Journal of Horticultural Science*, 58(1); pp. 103-109.

Muñoz, I.; Campra, P. y Fernández-Alba, A. M. (2010): «Including CO_2-emission equivalence of changes in land surface albedo in life cycle assessment. Methodology and case study on greenhouse agriculture»; *The International Journal of Life Cycle Assessment,* 15(7); pp. 672-681.

Muñoz, P.; Montero, J. I.; Antón, A. y Giuffrida, F. (1999): «Effect of insect-proof screens and roof openings on greenhouse ventilation»; *Journal of Agricultural Engineering Research* (73); pp. 171-178.

Nederhoff, E. M. (1988): «Dynamic optimization of the CO_2 concentration in greenhouses: an experiment with cucumber (Cucumis sativus l.)»; *Acta Horticulturae* (229); pp. 341-348.

Nederhoff, E. M. (1990): «Technical aspects, management and control of CO_2 enrichment in greenhouses»; *Acta Horticulturae* (268); pp. 127-138.

Nijskens, J.; Deltour, J.; Nisen, A. y Coutisse, S. (1984a): «Agronomic and radiometric characterization of greenhouse materials»; *Acta Horticulturae* (148); pp. 663-673.

Nijskens, J.; Deltour, J.; Nisen, A. y Coutisse, S. (1984b): «Proprietes radiometriques des materiaux plastiques»; *Acta Horticulturae* (154); pp. 33-42.

Nijskens, J.; Deltour, J.; Coutisse, S. y Nisen, A. (1989): «Radiometric and thermal properties of the new plastic films for greenhouse covering»; *Acta Horticulturae* (245); pp. 71-77.

Nisen, A. (1969): *L'éclairement natural de serres*. Edition I., Duculot, Gembloux (Belgica).

Nisen, A. y Coutisse, S. (1981): «Photometric poperties of double wall plastics used as covering for greenhouses»; *Acta Horticulturae* (115); pp. 85-97.

Nisen, A.; Nijskens, J.; Deltour, J. y Coutisse, S. (1984): «Determination des proprietes radiometriques des materiaux plastiques utilises en couverture des serres»; *Acta Horticulturae* (154); pp. 19-30.

Nisen, A.; Grafiadellis, M.; Jimenez, R.; La Malfa, G.; Martinez García, P. F.; Monteiro, A.; Verlodt, H.; de Villele, O.; Zabeltitz von, C. H.; Denis, I. C. y Baudoin, W. O. (1988): «Cultures protégées en climat méditerranéen»; *Étude FAO production végétale et protection des plantes* (90). Roma (Italia); p. 317.

Oka, Y.; Shapira, N. y Fine, P. (2007): «Control of root-knot nematodes in organic farming systems by organic amendments and soil solarization»; *Crop Protection* (26); pp. 1556-1565.

Papadakis, G.; Mermier, M.; Meneses, J. F. y Boulard, T. (1996): «Measurement and analysis of air exchange rates in a greenhouse with continuous roof and side openings»; *Journal of Agricultural Engineering Research* (63); pp. 219-228.

Papadakis, G.; Manolakos, D. y Kyritsis, S. (1998): «Solar radiation transmissivity of a single-span greenhouse through measurements on scale models»; *Journal of Agricultural Engineering Research* (71); pp. 331-338.

Papadopoulos, A. P. y Hao, X. (1997): «Effects of greenhouse covers on seedless cucumber growth, productivity, and energy use»; *Scientia Horticulturae* (68); pp. 113-123.

Papadopoulos, A. P. y Pararajasingham, S. (1997): «The influence of plant spacing on light interception and use in greenhouse tomato (Lycopersicon esculentum Mill.): A review»; *Scientia Horticulturae* (69); pp. 1-29.

Park, J. J.; Kim, J. K.; Park, H. y Cho, K. (2001): «Development of time-efficient method for estimating aphids density using yellow sticky traps in cucumber greenhouses»; *Journal of Asia-Pacific Entomology*, 4(2); pp. 143-148.

Parr, J. F. y Papendick, R. I. (1997): «Soil quality: relationship and strategies for sustainable dry land farming systems»; *Annals of Arid Zone* (36); pp. 181-191.

Pascual, J. A.; Hernandez, T. y Garcia, C. (1998): «Enzymatic activities in an arid soil amended with urban organic wastes. Laboratory experiment»; *Bioresource Technology* (68); pp. 255-264.

Peet, M. M.; Willits, D. H. y Gardner, A. E. (1997): «Response of ovule development and post-pollen production processes in male-sterile tomatoes to chronic, sub-acute high temperature stress»; *Journal of Experimental Botany,* 48(306); pp. 101-111.

Perdigones, A.; Pascual, V.; García, J. L.; Nolasco, J. y Pallarés, D. (2004): *Interactions of crop and cooling equipment on greenhouse climate*. GREENSYS 2004, 12-16 Septiembre, Leuven (Bélgica).

Piedra-Buena, A.; García-Alvarez, A.; Díez-Rojo, M. A.; Ros, C.; Fernández, P. y Lacasa, A. (2007): «Use of pepper crop residues for the control of root-knot nematodes»; *Bioresource Technology* (98); pp. 2846-2851.

Pirard, G.; Deltour, J. y Nijskens, J. (1994): «Gestion des écrans thermiques en serre»; *Plasticulture* (103); pp. 11-22.

Pivonia, S.; Cohen, R.; Levita, R. y Katan, J. (2002): «Improved solarization of containerized medium for the control of *Monosporascus* collapse in melon»; *Crop Protection* (21); pp. 907-912.

Plaisier, H. F. (1991): «L'importance d'écrans LS aluminisés pour la production de tomates, poivrons et aubergines en serre non chauffée»; *Plasticulture* (90); pp. 19-28.

PlastEuroFilm (1994): *Federatie der Chemische Nijverheid van België, Maria-Louisa Square* (49)B-1040. Bruselas (Bélgica).

Polizzi, G.; La Rosa, R.; Arcidiacono, C. y D'Emilio, A. (2003): «Effects of innovative films in soil solarization for the control of soil-borne pathogens»; *Acta Horticulturae* (614); pp. 805-811.

Pullman, G. S.; Devay, J. E. y Garber, R. H. (1981): «Soil solarization and thermal death: a logarithmic relantionship between time and temperature for four soil-bome pathogens»; *Phytopathology* (71); pp. 959-964.

Qiao, M.; Lim, J.; Ji, C. W.; Chung, B. K.; Kim, H. Y.; Uhm, K. B.; Myung, C. S.; Cho, J. y Chon, T. S. (2008): «Density estimation of *Bemisia tabaci* (Hemiptera: Aleyrodidae) in a greenhouse using sticky traps in conjunction with an image processing system»; *Journal of Asia-Pacific Entomology* (11); pp. 25-29.

Rampinini, G. (1989): «L'evoluzione dei sistemi di riscaldamento e raffrescamento»; *Colture Protette* (7); pp. 27-30.

Ray, S. J.; Wills, J. B.; Honea, G. S.; Buschermohle, M. J.; Straw, R. A. y Raman, D. R. (2005): «A one-year study of a supplemental air distribution system for greenhouses»; *Applied Engineering in Agriculture*, 21(5); pp. 915-924.

Rivera, J. (2000): *La Política de colonización en el Campo de Dalías*. Ed. Instituto de Estudios Almerienses y Caja Rural de Almería, Almería (España); p. 523.

Ros, M.; Hernández, M. T. y García, C. (2003): «Soil microbial activity after restoration of a semiarid soil by organic amendments»; *Soil Biology & Biochemistry* (35); pp. 463-469.

Ros, M.; García, C.; Hernández, M. T.; Lacasa, A.; Fernández, P. y Pascual, J. A. (2008): «Effects of biosolarization as methyl bromide alternative for *Meloidogyne incognita* control on quality of soil under pepper»; *Biology and Fertility of Soils* (45); pp. 37-44.

Rosocha, C. (1993): «Serres plastique non chauffées utilisées tout au long de lánnée en pépinière»; *Plasticulture* (97); pp. 33-40.

Salerno, M. L.; Lori, G.; Camporota, P. y Perrin, R. (1999): «Solarization for the control of soil-borne pathogens in forest nurseries in temperate climate»; *Journal of Plant Pathology* (81); pp. 95-102.

Sánchez-Hermosilla, J.; Rincón, V. J.; Páez, F. y Fernández, M. M. (2012): *Equipos para tratamientos fitosanitarios en invernaderos*. Consejería de Agricultura y Pesca, Instititúto de Investigacón y Formación Agraria y Pesquera, Almería (España); p. 17.

Sánchez-Hermosilla, J.; Páez, F.; Rincón, V. J. y Callejón, A. J. (2013): «Evaluation of a fog cooling system for applying plant-protection products in a greenhouse tomato crop»; *Crop Protection* (48); pp. 76-81.

Sánchez-Montero Sáez, A.; Cuadrado Gómez, I. M. y Juan Rodríguez, E. (1989): «Fechas de siembra y protección térmica en melón (Cucumis melo L.)». Jornadas Técnicas sobre los cultivos de melón y pepino. *Agrícola Vergel* (91); pp. 384-386.

Sase, S. y Christianson, L. L. (1990): «Screening greenhouses-Some engineering considerations»; Proceeding of the 1990 Northeast Agricultural/Biological Engineering Conference. 29 Julio-1 Agosto. Pennsylvania (EEUU); *ASAE*. NABEC: 90-201; p. 13.

Sase, S. (1989): «The effect of plant arrangement on airflow characteristics in a naturally ventilated glasshouse»; *Acta Horticulturae* (245); pp. 429-435.

Savé, R.; Peñuelas, J.; Marfá, O.; Montero, J. J.; Smart, D. y Biel, C. (1996): «El abonado carbónico en los cultivos protegidos»; *Hortoinformación* (81); pp. 42-45.

Scarascia-Mugnozza, G. (1995): «Sustainable greenhouse production in Mediterranean climate: a case study in Italy»; *MEDIT Prospettive e Proposte Mediterranee - Rivista di Economia, Agricoltura e Ambiente*, 6(4); pp. 48-53.

Schapendonck, A. H. C. M. y Tilburg, W. (1984): «The CO_2 factor in modelling photosynthesis and growth of greenhouse crops»; *Acta Horticulturae* (162); pp. 83-92.

Seginer, I. (1990): «Expected usefulness of CO_2 enrichment and shading in a desert climate»; *Acta Horticulturae* (268); pp. 149-156.

Seginer, I. (1997): «Alternative design formulae for the ventilation rate of greenhouses»; *Journal of Agricultural Engineering Research* (68); pp, 355-365.

Shukla, A.; Tiwari, G. N. y Sodha, M. S. (2006): «Thermal modeling for greenhouse heating by using thermal curtain and an earth-air heat exchanger»; *Building and Environment* (41); pp. 843-850.

Soni, P.; Salokhe, V. M. y Tantau, H. J. (2005): «Effect of screen mesh size on vertical temperature distribution in naturally ventilated tropical greenhouses»; *Biosystems Engineering*, 92(4); pp. 469-482.

Stapleton, J. J. (2000): «Soil solarization in various agricultural production systems»; *Crop Protection* (19); pp. 837-841.

Steiner, M. Y.; Spohr, L. J.; Barchia, I. y Goodwin, S. (1999): «Rapid estimation of numbers of whiteflies (Hemiptera: Aleurodidae) and thrips (Thysanoptera: Thripidac) on sticky traps»; *Australian Journal of Entomology* (38); pp. 367-372.

Streck, N. A.; Schneider, F. M. y Buriol, G. A. (1996): «Soil heating by solarization inside plastic greenhouse in Santa Maria, Rio Grande do Sul, Brazil»; *Agricultural and Forest Meteorology* (82); pp. 73-82.

Takakura, T.; Manning, T. O.; Giacomelli, G. A. y Roberts, W. J. (1994): «Feedforward control for a floor heat greenhouse»; *Transaction of the ASAE*, 37(3); pp. 939-945.

Tamietti, G. y Valentino, D. (2006): «Soil solarisation as an ecological method for the control of *Fusarium* wilt of melon in Italy»; *Crop Protection*, 25(4); pp. 389-397.

Taylor, R. A. J.; Shalhevet, S.; Spharim, I.; Berlinger, M. I. y Lebiush-Mordechi, S. (2001): «Economic evaluation of insect-proof screens for preventing tomato yellow curl virus tomatoes in Israel»; *Crop Protection* (20); pp. 561-569.

Teitel, M. y Shklyar, A. (1998): «Pressure drop across insect-proof screens»; *Transactions of the ASAE*, 41(6); pp. 1829-1834.

Teitel, M.; Barak, M.; Berlinger, M. J. y Lebiush-Mordechai, S. (1999a): «Insect-proof screens in greenhouses: their effect on roof ventilation and insect penetration»; *Acta Horticulturae* (507); pp. 25-34.

Teitel, M.; Segal, I.; Shklyar, A. y Barak, M. (1999b): «A Comparison between pipe and air heating methods for greenhouses»; *Journal of Agricultural Engineering Research* (72); pp. 259-273.

Teitel, M.; Shklyar, A.; Segal, I. y Barak, M. (1996): «Effects of nonsteady hot-water greenhouse heating on heat transfer and microclimate»; *Journal of Agricultural Engineering Research* (65); pp. 297-304.

Tesi, R. (1989): «Illuminazione ed ombreggiamento nelle serre»; *Colture Protette* (7); pp. 37-44.

Torrellas, M.; Antón, A.; López, J. C.; Baeza, E. J.; Pérez-Parra, J.; Muñoz, P. y Montero, J. I. (2012): «LCA of a tomato crop in a multi-tunnel greenhouse in Almeria»; *International Journal of Life Cycle Assessment* (17); pp. 863-875.

Torrellas, M.; Antón, A. y Montero, J. I. (2013): «An environmental impact calculator for greenhouse production systems»; *Journal of Environmental Management* (118); pp. 186-195.

Tzortzakakis, E. A. y Petsas, S. E. (2003): «Investigation of alternatives to methyl bromide for management of Meloidogyne javanica on greenhouse grown tomato»; *Pest Management Science* (59); pp. 1311-1320.

United Nations Environment Programme (UNEP) (1992): «Synthesis report of the methyl bromide interim scientific assessment and methyl bromide interim technology and economic assessment»; *Montreal Protocol Assess*. Junio 1992, UNEP, Nairobi (Kenya); p 33.

Urban, L. (1997): «Introduction à la production sous serre. Tome 1: La gestion du climat»; *TEC et DOC*. París (Francia); p. 320.

Urrestarazu, M. (2000): *Manual de cultivo sin suelo*. Edit. Mundi-Prensa, p. 648.

Valera, D. L.; Molina, F. D. y Gil, J. A. (1999a): «Análisis de la situación actual de los invernaderos de la provincia de Almería. Mejora de las condiciones ambientales como vía para la disminución del uso de pesticidas»; en *Conclusiones del encuentro medioambiental almeriense*. Universidad de Almería y Caja Rural de Almería, Almería (España).

Valera, D. L.; Molina, F. D. y Gil, J. A. (1999b): *Los invernaderos de Almería: Tipología y mecanización del clima*. Universidad de Almería, Almería (España); p. 268.

Valera, D. L.; Molina, F. D. y Gil, J. A. (2001): «Las mallas como técnica de control climático en invernaderos»; *Vida Rural* (139); pp. 50-52.

Valera, D. L.; Molina, F. D. y Peña, A. (2002a): *Climatización de invernaderos*. Servicio de Publicaciones de la Universidad de Almería. Almería (España); p. 233.

Valera, D. L.; Molina, F. D. y Gil, J. A. (2002b): «Sistemas de ventilación cenital utilizados en los invernaderos»; *Vida Rural* (152); pp. 42-45.

Valera, D. L.; Molina-Aiz, F. D.; Álvarez, A. J.; Peña, A. y López-Gálvez, J. (2004): «Sistemas de protección de cultivos en invernaderos: la experiencia española»; en Acuña J.F., Valera D.L. y Avendaño J.C., ed.: *Invernaderos: La experiencia Iberoamericana. Desarrollo de sistemas de protección de cultivos para zonas cálidas e intertropicales: competitividad y sostenibilidad*. Proyecto Nº: XIX.2 Estructuras de Protección para Zonas Intertropicales, Ciencia y Tecnología para el Desarrollo (CYTED), Almería (España); pp. 131-152.

Valera, D. L.; Álvarez, A. J. y Molina-Aiz, F. D. (2006): «Aerodynamic analysis of several insect-proof screens used in greenhouses»; *Spanish Journal of Agricultural Research*, 4(4); pp. 273-279.

Valera, D. L.; Molina-Aiz, F. D. y Álvarez, A. J. (2008a): «Ahorro y eficiencia energética en invernaderos»; *Eficiencia y ahorro energética en la Agricultura* (7). Instituto para la Diversificación y Ahorro de la Energía (IDAE), Ministerio de Industria, Turismo y Comercio. Madrid (España); p. 64.

Valera, D. L.; López, A.; Molina-Aiz, F. D. y Marín, P. (2013): *Estudio de la eficacia de un sistema de calefacción por combustión indirecta en la distribución de calor en un invernadero*. VII Congreso Íberico de AgroIngeniería y Ciencias Hortícolas, 26 al 29 de agosto 2013, Madrid (España): Comunicación C0293.

Van Zundert, T. (2012): «Life Cycle Assessment (LCA) of the Dutch greenhouse tomato production system»; *Masters of Agricultural and Bioresource*, University of Wageningen (Holanda); p. 66.

Verheye, P. y Verlodt, H. (1990): «Comparison of different systems for static ventilation of hemispheric plastic greenhouses»; *Acta Horticulturae* (281); pp. 183-197.

Von Elsner, B.; Briassoulis, D.; Waaijenberg, D.; Mistriotis, A.; Zabeltitz von C.; Gratraud, J.; Russo, G. y Suay-Cortes, R. (2000a): «Review of structural and functional characteristics of greenhouses in European Union countries: Part I, Design Requirements»; *Journal of Agricultural Engineering Research* (75); pp. 1-16.

Von Elsner, B.; Briassoulis, D.; Waaijenberg, D.; Mistriotis, A.; Zabeltitz von C.; Gratraud, J.; Russo, G. y Suay-Cortes, R. (2000b): «Review of structural and functional characteristics of greenhouses in European Union countries: Part II, Typical Design»; *Journal of Agricultural Engineering Research* (75); pp. 111-126.

Von Zabeltitz, C. (1992): «L'efficacité énergétique dans la conception des serres méditerranéennes»; *Plasticulture* (96); pp. 6-16.

Wacquant, C. (2000): «La construction des serres et abris»; *Centre Technique Interprofessionnel des Fruits et Légumes (CTIFL)*. Francia; p. 207.

Wai, K. S. y Newman, S. E. (1992): «Air and root-zone temperatures influence growth and flowering of snapdragons»; *HortScience*, 27(7); pp. 796-798.

WALKER, J. N. y COTTER, D. J. (1968): «Cooling greenhouses with various water evaporative systems»; *Transactions of the ASAE* (11); pp. 116-119.

WELLS, C. M. y AMOS, N. D. (1994): «Design of air distribution systems for closed greenhouses»; *Acta Horticulturae* (361); pp. 93-104.

WILLIAMS, A. G.; AUDSLEY, E. y SANDARS, D. L. (2006): «Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities»; *Main Report. Defra Research Project IS0205*. Cranfield University and Defra, Bedford (Reino Unido); p. 97. (Disponible en: www.defra.gov.uk).

WITZGALL, P. (2001): *Pheromones - future techniques for insect control? Pheromones for Insect Control in Orchards and Vineyards IOBC wprs Bulletin*, 24(2); pp. 114-122.

WITZGALL, P.; KIRSCH, P. y CORK, A. (2010): «Sex pheromones and their impact on pest Management»; *Journal of Chemical Ecology* (36); pp. 80-100.

Annex. Survey model

Survey on greenhouse infraestructure and its relationship with economic profitability

The Cajamar Chair of Economics and Agri-Food is conducting an «An empirical study of the correlation between productive greenhouse infrastructures and economic profitability». This questionnaire is aimed at farmers who have holdings in any of the following agricultural regions: Campo de Dalías, Bajo Andarax, Campo de Níjar and Bajo Almanzora. This survey is completely anonymous, and you have been randomly selected, so please answer with the utmost sincerity.

Surveyor: ______________________ Interview (id): __________

survey location: __________________________________

A.- Personal data

P.1 Age ______

P.2 Years dedicated to agriculture ________

P.3 The farmer is:

In partnership with the owner	1
Owner	2
Tenant	3
N/A	15

P.4 Geographic origin of the holder:

Native of the area	1
Non native	2
N/A	15

P.5 Education level

None	1
Primary education	2
Hight school graduate	3
University	4
Courses	5
Others	6
N/A	15

P.6 Do you have additional employment or another business occupation?

No	1
Yes	2
N/A	15

If so, what type? ______________________

P.7 Occupational origin of the farmer (profession before becoming a farmer)

Always a farmer		1
Previous work experience:	Construction	2
	Auxiliary industry	3
	Hotel trade and other services (please specify): ______________	4
Ns/Nc		15

P.8 Geographic location of the farm:

Town: ______________________

Place: ______________________

P.9 Total area of the farm or farms (if more than one):

Under mesh ______________________

Under plastic _________________________

Open air ____________________________

B.- Crops

P.10 How is weed control performed?:

Tools	1
Hand	2
Herbicide	3
Hand and herbicide	4
Hand and tools	5
None	6
N/A	15

P.11 How is sowing performed?

Direct	1
Seedlings	2
N/A	15

Crops for which direct sowing is practiced ______________

P.12 Who conducts seedling preparation?

Farmer	1
Seed box	2
Other	3
N/A	15

P.13 Who conducts foliar analysis?

Not conducted	1
Farmer	2
Cooperative	3
Other (specify): ______________	4
N/A	15

If so, at what frequency? ____________________

P.14 What crop is currently sown? (species and variety)

Autumn ________________________

Spring ________________________

Long cycle ________________________

P.15 ¿Qué cultivó la campaña pasada? (especie y variedad)

Autumn ________________________

Spring ________________________

Long cycle ________________________

P.16 ¿Qué cultivó hace dos campañas? (especie y variedad)

Autumn ________________________

Spring ________________________

Long cycle ________________________

P.17 Orientation of the crop lines

Following the direction of the ridges or raspas (longitudinal)	1
Perpendicular to the ridges or raspas (transversal)	2
Other (specify) ____________________	3
N/A	15

P.18 Planting framework

Tomato ________________

Cucumber ________________

Pepper ________________

Zucchini ________________

Green bean ________________

Watermelon ________________

Melon ________________

Eggplant ________________

P.19 Average yield obtained for each crop

Season	Crop	kg/m^2 (commercial, without discard)

P.20 Is a phytosanitary treatment system or substitute used?

Hormonal attractants	1
Colour attractants	2
Integrated control	3
Biological control	4
Organic crop	5
Other (specify)	6
N/A	15

P.21 Are pollination methods used?

No	1
Yes	2
N/A	15

If so, which methods?

Bees	1
Bumblebees	2
Air	3
Other	4
N/A	15

If so, for what crops? ________________________

P.22 Are grafts used in your holding?

No	1
Yes	2
N/A	15

If so, for what crops? ______________________________________

C.- Machinery

P.23 What type of machinery is used for the application of phytosanitary treatments?

Fixed applicators	Fogging nozzles		1
	Hose + gun (hooked to a fixed pipe)		2
	Other (specify)		3
Aplicadores portátiles	Canon		4
	Cart		5
	Backpack		6
	Treatment machine	Over-heating rails	7
		On wheels	8
	Other (specify)		9
None			10
N/A			15

P.24 What types of vehicles are usually used on the farm?

Tourism	1
Van	2
All terrain	3
Truck	4
Motorcycle	5
Bicycle	6
Tractor	7
None	8
N/A	15

P.25 Are machinery and operators rented or contracted for land-preparation work?

No	1
Yes	2
N/A	15

P.26 What types of labour require renting or contracting machinery and operators?

General broadcasting	1
Banding	2
Cleaning	3
Placement of the irrigation system	4
Sulphating or dusting of the soils and structures	5
Tilling of the soil	6
None	7
N/A	15

P.27 How often is land preparation performed?

Every season	1
Every 2 seasons	2
More than 2 seasons	3
N/A	15

D.- Soil

P.28 Are soil analyses conducted?

No	1
Yes	2
N/A	15

P.29 Is soil disinfection conducted?

No	1
Yes	2
N/A	15

If so, what type of disinfection is performed?

Solarisation (water + plastic)	1
Only soil disinfection (metam sodium, dichloropropene, chloropyramine, etc.)	2
Solarisation + soil disinfection (at lower doses of metam sodium, dichloropropene, etc.)	3
Biofumigation (only in organic matter, which ferments in the soil and disinfects)	4
Biosolarisation (plastic + organic matter)	5
Others (especify: ______________________)	6
N/A	15

If so, at what frequency?

1 Year	1
2 Years	2
More than 2 years	3
N/A	15

P.30 Soil type

Natural original	1
Sanded	2
Stubble	3
Mulching	4
Hydroponic	5
Other (specify)	6
N/A	15

For hydroponic systems, what is the substrate type?:

Rockwool	1
Perlite	2
Vermiculite	3
Coco fibre	4
Other (specify): ____________________	5
N/A	15

What is the system type?:

Recirculating	1
Non-recirculating	2
N/A	15

P.31 Is broadcasting performed?

No	1
Yes	2
N/A	15

If so, on how much of the surface?

Entire surface	1
Banding	2
N/A	15

At what frequency?

1-2 years	1
3-4 years	2
More than 5 years	3
N/A	15

What type?

Chicken	1
Sheep	2
Bovine	3
Compost	4
Prepared sacks	5
Others (specify) ____________________	6
N/A	15

P.32 Approximate cost of broadcasting __________________________ Euros/kg

P.33 Amount contributed ____ kg/m^2

P.34 Approximate wages for broadcasting ___________________ Jornales/ha

P.35 Are humic acids added?

No	1
Yes	2
N/A	15

P.36 Have you considered changing from sanded to hydroponic, or vice versa?

No	1
Yes (specify the change: from ________________ to ________________	2
N/A	15

E.- Edificaciones auxiliares/sistema de riego

P.37 Auxiliary buildings

Storage sheds	Surface ____________________	1
Irrigation huts	Surface ____________________	2
Irrigation pond	Surface ____________________	3
N/A		15

P.38 Type of pond

Concrete	1
Earth and plastic	2
Others (specify) ____________________	3
N/A	15

P.39 Shape of the pond

Cylindrical	1
Cubic	2
Triangular	3
Rectangular	4
Square	5
N/A	15

P.40 Type of filter

Sand	1
Disc	2
Ring	3
Others (specify) ____________________	4
N/A	15

P.41 Is rain water collected?

No	1
Yes	2
N/A	15

Interior of the greenhouse	1
Exterior of the greenhouse	2
N/A	15

P.42 What irrigation system is installed?

Blanket	1
Sprinkler	2
Drip	3
Hydroponic (drip + peg)	4
N/A	15

P.43 Are water analyses performed?

No	1
Yes	2
N/A	15

P.44 Are tensiometers used?

No	1
Yes	2
N/A	15

P.45 Water source

	Proportion	**Cost (€/m^3)**	**Electrical conductivity (dS/m)**	
Farm well				1
Communal well				2
Irrigation community				3
Desalinated water				4
N/A				15

If you have your own well, what is the daily cost of diesel oil or electricity? ________

P.46 Is an irrigation controller installed?

No	1
Yes	2
N/A	15

P.47 Is a pump used in the irrigation system?

No	1
Yes	2
N/A	15

How is it powered? ____________________

What type of power?

Diesel	1
Electric	2
N/A	15

P.48 How is fertilisation performed?

Spreader	1
Venturi	2
Injectors	3
Broadcast	4
Others (specify) ____________________	5
N/A	15

F.- Marketing

P.49 Where is your product sold?

Exchange	1
Cooperative	2
SAT	3
Private distributor	4
Others (specify) ____________________	5
N/A	15

P.50 Are all of your products brought to the same location?

No	1
Yes	2
N/A	15

P.51 Are you a member of a cooperative?

No	1
Yes	2
N/A	15

How many years have you been a member?

< 2 years	1
2-5 years	2
5-10 years	3
>10 years	4
N/A	15

P.52 Do you receive any type of advice?

No	1
Yes	2
N/A	15

If so, what type?

Private	1
Provisions	2
Nursery	3
Cooperative	4
N/A	15

P.53 Do you prepare the product before transporting it to the point of sale?

No	1
Yes, by hand	2
Yes, by machine (specify): ________________________________	3
N/A	15

Time (%) dedicated to preparing the product during the harvest period: ______________________ %

P.54 Is the product subject to a certification system or standards for agricultural field practices?

No		1
Si	Global Gap	2
	UNE 155.000 (AENOR)	3
	Naturane (ANECOOP)	4
	Integrated production (e.g., Council of Andalucía)	5
	Other (e.g., supermarket chains) (specify):	6
N/A		15

G.- Estructura

P.55 Number of greenhouses on the farm

One	1
Two	2
Three	3
More than three	4
N/A	15

P.56 Year of construction of the greenhouse (most representative) ________

P.57 Approximate construction costs of the greenhouse(s) ______ euros/m^2

P.58 Type of greenhouse

Type Almería (Flat-top)	1
Type Almería ('raspa y amagado')	2
Type Almería (Asymmetric)	3
Multi-span cylindrical Type	4
Multi-span gothic Type	5
Venlo	6
Mesh	7
Other (specify) ________________	8
N/A	15

P.59 Geometry of the greenhouse

Rectangular shape	1
Irregular shape	2
N/A	15

Surface (m^2): ______________________________

Average length (m): ______________________________

Average width (m): ______________________________

Number of imbalances: ______________________________

P.60 Type of interior support

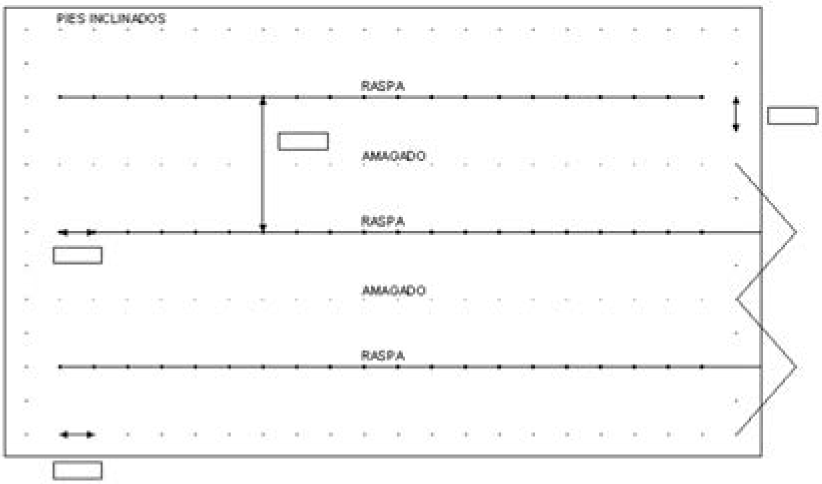
Wooden supports	1
Metal tubes	2
Steel beam	3
Profile (specify dimensions): ____________________	4
Others (especify) ____________________	5
N/A	15

P.61 Type of perimeter support

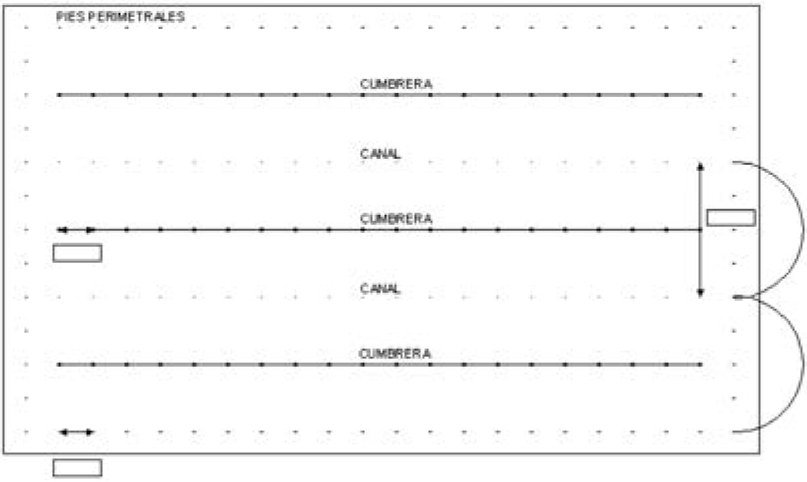
Wooden poles	1
Metal tubes	2
Steel beam	3
Profile (specify dimensions): ____________________	4
Others (especify) ____________________	5
N/A	15

P.62 Separation between supports:

For the Almería greenhouse



For the multi-span greenhouse



P.63 Greenhouse height

Maximum (ridge) ______________________ m

Minimum (gutter) ______________________ m

Perimeter (bands) ______________________ m

P.64 Have you changed the height of the greenhouse?

No	1
Yes	2
N/A	15

What height was it previously? Maximum ______________ m

Minimum ______________ m

P.65 Greenhouse orientation (principle axis, ridges, and raspas)

North-south (N-S)	1
East-west (E-W)	2
Other (specify) ______________	15

P.66 Dimensions of the central corridor

Width ______________________________ m

Length ______________________________ m

Free height of the corridor ______________________ m

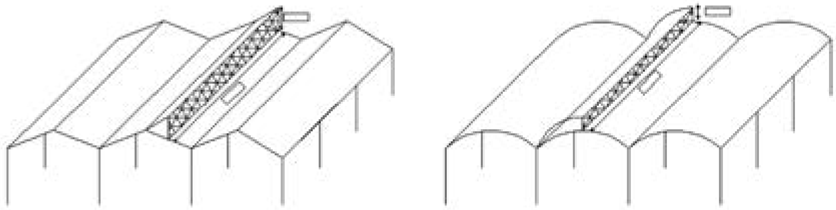
P.67 Orientation of the corridor

Following the direction of the ridges or raspas (longitudinal)	1
Perpendicular to the ridges or raspas (transversal)	2
Other (specify) ______________	15

P.68 Is roof ventilation installed?

No	1
Yes, in all the raspas or modules	2
Yes, in alternating raspas or modules	3
Others (specify) ____________________	4
N/A	15

Dimensiones:



P.69 Type of roof windows

Without roof ventilation	1
Sliding window moving the plastic	2
Folding window	3
Rolling window	4
Pyramidal window	5
Fixed opening	6
Superzenith	7
Half arch	8
Set-off half arch	9
Butterfly	10
Centered	11
Others (especify) ________________________________	12
N/A	15

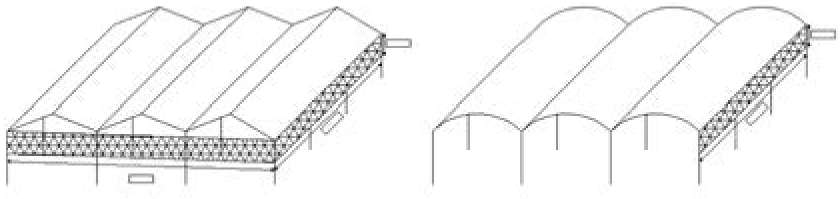
P.70 Operation of roof windows

Manual	1
Semiautomatic (manually operated motor)	2
Automatic (motor operated by climate controller)	3
Fixed opening	4
Other (especify) __________________________	5
N/A	15

P.71 Is lateral ventilation installed?

No	1
Yes, # of bands with windows: __________________________	2
N/A	15

Dimensions:



P.72 Type of lateral windows

No lateral ventilation	1
Sliding lateral bands	2
Sliding window (pulleys)	3
Roll-up window	4
Folding window	5
Others (especify) __________________________	6
N/A	15

P.73 Operation of lateral windows

Manual	1
Semiautomatic (manually operated motor)	2
Automatic (motor operated by climate controller)	3
Fixed opening	4
Others (especify) ____________________	5
N/A	15

P.74 Does the greenhouse have a double door?

No	1
Yes	2
N/A	15

P.75 Does the greenhouse have a double roof?

No	1
Yes	2
N/A	15

If so, what type?

White plastic	1
Thermal blanket	2
OThers	3
N/A	15

P.76 Types of insect-proof screens in the lateral windows

Nothing	1
Mosquito fabric (10 × 16 threads/cm)	2
Standard fabric (10 × 20 threads/cm)	3
Antithrip fabric (15 × 30 threads/cm)	4
Other (indicate density): __________ × __________ threads/cm	5
N/A	15

Colour: ____________________

P.77 Types of anti-insect mesh in the roof windows

Nothing	1
Mosquito fabric (10 × 16 threads/cm)	2
Standard fabric (10 × 20 threads/cm)	3
Antithrip fabric (15 × 30 threads/cm)	4
Other (indicate density): ____________ × ____________ threads/cm	5
N/A	15

Colour: ______________________________

P.78 Plastic thickness ______________________________ gauge

P.79 What type of cover material is installed?

Tri-layer plastic (PE-EVA-PE)	1
Low density polyethylene (PEld)	2
Mesh	3
Glass	4
Others: (especify) ______________________________	5
N/A	15

Company: ______________________________

Brand and model: ______________________________

P.80 Characteristics of the cover material

Thermal plastic	1
Photoselective	2
Anti-drip	3
OThers: (especify) ______________________________	4
N/A	15

P.81 Colour of the plastic ______________________________

P.82 Duration of the plastic ____________________________________

P.83 Cost of the plastic ______________ euros/m^2 ______________ euros/kg

P.84 Who applies the plastic?

Farmer and neighbours	1
Group	2
Others: (especify) ____________________________	3
N/A	15

P.85 Who removes the plastic?

Farmer and neighbours	1
Group	2
Others: (especify) ____________________________	3
N/A	15

P.86 Is the roof whitewashed?

No	1
Yes	2
N/A	15

If so, when? ____

For what crop? ____

What product do you use? __________________________________

What dose?:

When the plastic is new? ________________________

When the plastic is a season old? _______________

When the plastic is more than one season old? ________

P.87 How is the roof cleaned?

Natural (rain, wind, etc.)	1
Water at pressure	2
Brush + wind	3
Brush + water	4
Cleaning machine	5
Other: (especify) ______________________	6
N/A	15

H.- Climate control system

P.88 Is a climate-control system installed?

No	1
Yes	2
N/A	15

Company: ______________________________________

Brand: ______________________________________

Model: ______________________________________

What measurements? ______________________________________

P.89 What type of screen is used?

None	1
Thermal screen	2
Shading mesh	3
Mixed screen (thermal and shading)	4
Other (especify) ______________________	5
N/A	15

P.90 What type of forced ventilation system is installed?

None	1
Extractors	2
Destratification fans (interior)	3
Other (especify) ____________________	4
N/A	15

P.91 What type of water evaporative cooling system is installed?

None	1
High-pressure fog system (metal pipes)	2
Low-pressure fog system (only water)	3
Mixed fog system compressed air + water	4
Pad-and-fan system (Cooling system)	5
Other (especify) ____________________	6
N/A	15

P.92 Heating system

None		1
By water	Radiant soil (buried pipes)	2
	Pipes under trays (nursery)	3
	Metal pipes on the ground (rails)	4
	Plastic pipes over the ground	5
	Aerial pipes of metal	6
	Aerial pipes of plastic	7
	Other (specify):	8
By air	Direct combustion heaters	9
	Indirect combustion heaters	10
	Polyethylene sleeve	11
	Other (specify):	12
Other (especify) ____________________		13
N/A		15

Maximum heating power: __________ kW or __________ CV

P.93 What type of fuel is used for the heating system?

Natural gas	1
Diesel oil	2
Biofuel (specify) ____________	3
Propane	4
Other (especify) ____________________	5
N/A	15

P.94 What type of energy saving techniques are employed?

None	1
Plastic tunnel	2
Thermal blanket	3
Double roof	4
Double walls	5
Variable frequency (specify for what: ____________)	6
Other (especify) ____________________	7
N/A	15

P.95 Are other advanced climate control systems installed?

None	1
CO_2 injection	2
Photoperiod artificial lighting	3
Photosynthetic artificial lighting	4
Cogeneration (specify)____________________	5
Other (especify) ____________________	6
N/A	15

I.- Cost benefit analysis

P.96 What is your income at the end of the year or season?

__________€/m²

__________€/kg

__________€

P.97 What are your approximate expenses during the year?

__________€/m²

__________€/kg

__________€

P.98 What crops tend to produce higher net profits?

1º ______________________________

2º ______________________________

3º ______________________________

P.99 What crops require the greatest investment at the beginning and throughout the season?

1º ______________________________

2º ______________________________

3º ______________________________

P.100 Have you been granted any type of subsidy?

No	1
Yes	2
N/A	15

If so, by what entity? ______________________________

P.101 Have you been granted any type of financing?

No	1
Yes	2
N/A	15

If so, by which bank? ______________________

J.- Labour

P.102 Who performs the labour?

Self-performed (family members)	1
External labour	2
N/A	15

P.103 What type of labour is hired?

Permanent (all year), number: __________	1
Permanent discontinuous (seasonal personnel), number: __________	2
Temporary, number: __________	3
Not contracted	4
N/A	15

P.104 When is temporary personnel hired?

Land preparation, number: __________	1
Sowing, number: __________	2
Fruit collection, number: __________	3
Trellising, number: __________	4
Cleaning, number: __________	5
Other (specify): __________ number: __________	6
N/A	15

P.105 Do you have any type of hiring preference?

Sex	1
Age	2
Nown	3
Immigrants	4
None	5
N/A	15

P.106 Do you hire immigrant workers?

No	1
Yes	2
N/A	15

P.107 Have you considered performing short-term improvements on your farm?

No	1
Yes	2
N/A	15

If so, what type? ________________________________

P.108 Do you believe that this survey can help increase the cooperative knowledge of production and that subsequent analysis of the results can improve the systems used?

No	1
Yes	2
N/A	15

Notes (relevant facts): Weather (e.g. extreme rain or winds, dates), increase of inputs, abnormal sales prices, etc.