Mediterranean Greenhouse Technology

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Greenhouse cultivation can provide high-quality product all-year round with an efficient use of resources, such as water, fertilisers, pesticides and hand-labour. Consequently, in the last decades protected cultures have developed rapidly in many regions, in particular (but not only) in the Mediterranean Basin countries, where the mild temperature during winter makes it possible to produce low-cost vegetable crops in very simple shelters. The low-technology protected horticulture industry has allowed the economic development of several marginal (poor) regions, such as Almeria, Spain. However, in the Mediterranean Basin there is need for technological updating of greenhouse industry in order to face the increasing competition arising from globalisation of both production and marketing. Moreover, the enhanced awareness of environmental pollution provoked by agriculture, the increasing demand of healthy foods and - last, but not least - the shortage of resources like water, are forcing the growers to introduce more sustainable growing techniques. The reduction of production costs and an improved marketing of traditional vegetables seem more needed than looking for new crops. In general, Mediterranean Basin greenhouse growers must aim to produce, in an environmentally friendly way, high quality standard products, rather than low-price commodities; the use of modern greenhouses (with better climate control and more advanced growing technologies such as drip fertigation, hydroponics and integrated pest management) and seawater for irrigation are the most relevant aspects of this development. Proper education and training of growers are also needed, and eventually a new generation of entrepreneurs, less conservative and more professional.

HISTORICAL

Commercial protected horticulture appeared first in Northern Europe in the early decades of the last century and developed broadly after World War II. By using heated glasshouses equipped with sophisticated cultivation systems, growers intended to overcome the problem of cultivating cold-sensitive species during most of the year. After the advent of plastics in the early 1960s, greenhouse crops started to move to mild-winter regions such as Mediterranean Basin countries (in particular, Italy, Spain and Morocco). The rise in oil prices in the 1970s, which increased the heating costs, further enhanced the diffusion of greenhouse crops in the Southern countries. More recently, protected crops expanded to some Asian countries such as India, Korea and, especially, China (Jiang et al., 2004).

Reliable statistical data of protected horticulture at a world level are quite difficult to find, since the sector is quite dynamic and changes rapidly. Moreover, in many countries (including most of the Mediterranean Basin) there is not a central council in charge of recording the area of protected crops; data are generally provided by sources such as growers associations and public institutions, often with little consistency. According to one of the most recent and comprehensive reports (Jouet, 2001), by 2000 there were nearly 700,000 hectares covered by greenhouses and large tunnels and nearly another million of hectares using low tunnels or direct covers. However, this value did not consider the quite recent explosion of greenhouse industry in China, which now has something like 1.5 million of tunnels and greenhouses (Jiang et al., 2004). Therefore, we estimate more than 2.0 millions hectares for worldwide protected horticulture.

The huge growth of worldwide protected horticulture in the last decade (the sector has increased by 30-40% since 1991) is the result of three main factors. Firstly, the demand of high-quality horticultural products, including out-of season and exotic products (not only food!), has increased substantially, particularly in Europe. Secondly, the improved technology of transportation and postharvest storage has allowed the production in areas far from the main markets and the commercialisation of many products all-year round. Thirdly, greenhouse industry may lead to economic development of marginal regions in mild-winter climate, as it makes economically-efficient use of many resources, such as land, labour and water. The gross income from protected horticulture may reach values of $50,000-$100,000/ha, up to more than $500,000/ha in case of potted ornamental plants. The relevance of greenhouse industry for economic development is not limited to cash-earnings: besides links to other industries (food processing, supply of technical means and services)

Figure 1. The satellite image of the protected crops located in Almeria (Spain). (Image courtesy of Earth Sciences and Image Analysis Laboratory, NASA Johnson Space Center, http://eol.jsc.nasa.gov, image number: ISS005-E-6663.JPG).

protected crops may provide good opportunities for job in regions of emigration (e.g. Northern Africa).

Almeria, Spain with more than 30,000 hectares of plastic greenhouses (the largest concentration of greenhouses in the Mediterranean Basin) is an outstanding example of the economic influence of protected culture (Fig. 1). Protected horticulture is responsible for the astonishing economic growth of this province in the last 20 years (from third from the bottom to third from the top in the economic ranking of Spanish provinces) (Stanghellini et al., 2003). The sector now provides employment to more than 80.000 people and produces roughly 40% of the Gross Provincial Product (Costa and Heuvelink, 2000). The province of Ragusa (Fig. 2), in Sicily (Italy), is another area where greenhouse horticulture is one important source of income for local population; since the 1960s about 6,000 hectares have been covered by plastic greenhouses and tunnels, mostly for vegetable production.

Cornpared to field crops protected horticulture markedly increases water use efficiency (WUE), as expressed both in terms of yield (Table 1) and gross income (up to some tens of euros per cubic meter of irrigation water). This is the result of reduced potential evaporation since the indoor climate is characterised by higher humidity and less radiation and wind than outside, increased crop yield, and the application of advanced irrigation technologies (such as drip irrigation and hydroponics).

Figure 2. Plastic greenhouses and tunnels in Pachino (Ragusa, Sicily, Italy) in the 1960s.

Table 1. Water use efficiency (WUE) of tomato crops carried out under different climatic conditions and using different growing systems.

Growing conditions	Country	WUE (kg m^{-3})
Field	Israel (soil culture)	17[1]
	France (soil culture)	14[1]
Unheated plastic greenhouse	Spain (soil culture)	25
	France (soil culture)	24
	Israel (soil culture)	33
	Italy (open substrate culture)	23
	Italy (closed substrate culture)	47
Climate-controlled soilless greenhouse	France (open-system)	39[2]
	Netherlands (open system)	45
	Netherlands (closed system)	66

Source: [1] Van Os, 2001; [2] Baille, 2001; [3] Malorgio et al., 1991; [4] Malorgio et al., 2001

Greenhouse Cultivation Technologies

Different kinds of protection are currently used for growing vegetables, cut flower, pot plants, propagation materials (seedlings, rooted cuttings, ex vitro young plants, etc.), and fruit crops. According to Tognoni et al. (1999), three main greenhouse types can be identified, as follows.

Low-technology greenhouses (LTG). The investment cost is lower than 25-30 $/m^2. LTG have very simple structure, plastic covering, poor climate control and, very often, lack heating system. Vegetables and low-value cut flowers are grown under this kind of shelters with simple growing methods that are similar or just the same as those used in open field.

Medium-technology greenhouses (MTG). The investment cost ranges between 30 and 100 $/m^2. MTG use metal structure and both plastic (often, rigid pans) and glass as covering materials. Climate control is more efficient compared to LTG, thus the internal environment is relatively independent from the external one. More advanced growing technologies, including hydroponics, are used in MTG, where many operations are partially or fully automated. MTG are quite flexible from the technical viewpoint and are generally employed for out-of-season vegetables, high-value cut flowers (roses, for instance) and ornamental pot plants.

High-technology greenhouses (HTG). The investment is higher than 100 $/m^2 and may reach 200 $/m^2 and more. HTG are generally built with galvanised iron support structure and glass as covering material. HTG have a sophisticated climate control system based on both air and root zone heating, forced ventilation, evaporative cooling, humidity control, light conditioning (shading and artificial lighting) and carbon dioxide enrichment; thus, the indoor climate can be completely independent from outdoors (Fig. 3). In HTG growing systems are set up to maximise space-use efficiency and minimise hand labour for product unit. HTG are used mostly for ornamentals and nursery production in cold winter regions.

At the world level, the scientific and technological development in protected horticulture is currently directed to the design of more sustainable cropping techniques that must supply high-quality products to more and more exacting consumers. The trend is towards the application of a more advanced technology for better climate control and a lesser use of water and agrochemicals. Integrated management of pest and diseases (IPM), drip irrigation and fertigation are increasingly used, while soilless cultures are spreading very slow because of the huge investment costs, which are too risky for small-scale enterprises in the current economical scenario. The application of fertigation has resulted in the installation of many automated systems for the preparation and the delivery of the culture solution. On the contrary, the computer-assisted climate control is still rare and mostly restricted to the cultivation of pot plants.

Figure 3. High-tech greenhouse for soilless production of tomatoes in Almeria (Spain).

Table 2. Protected horticulture (area in hectares) in the Mediterranean Basin.

Country	Greenhouses & large plastic tunnels (a)	Glasshouses (b)	Total walk-in structures (a+b)	Low tunnels	Total protected area	Soilless culture
Algeria	5,000		5,000	800	5,800	
Cyprus	285		285	300	585	
Egypt	1,350		1,350	50,000	51,350	10
France	9,000	2,300	11,300	16,000	27,300	
Greece	3,000	2,000	5,000	4,500	9,500	200
Israel	4,530	150	4,680	15,000	19,680	1,200
Italy	61,900	5,800	67,700	24,000	91,700	700
Morocco	10,000	550	10,550		10,550	
Spain	51,000	4,800	55,800	17,500	73,300	4,000
Tunisia	1,300		1,300	11,000	12,300	30
Turkey	20,900	6,200	27,100	1,500	28,600	
Total	168,265	21,800	190,065	140,600	330,665	6,140

Source: Jouet, 2001

Table 3. Production cost and income for sweet pepper crop in Holland and in Almeria.

Variable	Soil culture (Almeria)	Soilless culture (Almeria)	Soilless culture (Holland)
Yield (kg/ha)	105 000	160 000	260 000
Market price (€/kg)	0.53	0.66	1.62
Gross income (€/ha)	56 000	106 000	421 000
Variable costs (€/ha)	31 000	38 000	265 000
Fixed costs (€/ha)	13 000	27 000	55 000
Capital costs (€/ha)	4 000	8 000	60 000
Net income (€/ha)	8 000	33 000	41 000

Source: Stanghellini et al., 2003

THE MEDITERRANEAN BASIN GREENHOUSE INDUSTRY

Area and Crops

In the Mediterranean Basin, the world's most important vegetable production district, the area devoted to protected horticulture crops went from nil in the 1950s to some 120,000 ha in 1985 and nowadays there are about 170,000 hectares of greenhouses and large tunnels (Table 2). The countries with the largest area are France, Italy, Spain, and Turkey. Protected horticulture extended on more than 300,000 hectares, if low tunnels are considered; low tunnels are most common in Egypt, France, Italy and Turkey. Including temporary protections, like direct covers with wooden-nonwooden material, will increase further the area of Mediterranean Basin protected horticulture. The use of glasshouses is quite limited (something like 10,000 ha, according to Castilla, 2002) and restricted to ornamentals and nursery crops.

Vegetable crops are more important than floriculture, although the cultivation of cut flowers is quite extended and rapidly increasing in some regions, such as Israel, Turkey and Sicily. In Israel, cut flowers and ornamentals are grown on nearly half of the greenhouse acreage. There are also examples of protected fruit crops like banana (Morocco, Spain and Turkey), peach, plum and table grape. Protected culture of table grapes is necessary in many countries, particularly Italy; temporary protections are used with the aim to anticipate or postpone the harvest and to protect the grape from rain.

Solanaceous fruits (tomato, pepper and eggplant) and cucurbits (melon, zucchini, watermelon) crops account for more than 80% of the protected area. The reasons for the diffusion of these crops are the large market demand, the adaptability to variable climatic conditions of unheated shelters and to long-distance transportation, and the extended cycle that enhances the exploitation of the greenhouse. Typically, growers start their crops planting hybrid-seed transplants that are increasingly produced by specialised nurseries. Tomato (round, cluster, cherry, long-shape types are most common) is the most important product, which is predominantly marketed to Northern Europe. Strawberry is another important crop grown under unheated plastic shelters (both walk-in and low tunnels).

From the economic point of view, vegetable products are constantly increasing, but their relative prices are decreasing (La Malfa and Leonardi, 2002). The production costs are reduced compared to the North-European regions due to the lower cost of land, labour and shelters (Table 3). Furthermore, there are less environmental restrictions or, at least,

there is a less rigid control by public authorities. However, transportation cost is much higher; for vegetables its incidence may reach up to more than 50% of the overall cost, compared to 20-25% for Northern productions. Finally, many areas are increasingly afflicted by the problem of water scarcity and salinisation.

In most countries, greenhouse producers are family companies, which are characterised by the low cost of hand-labour and the strong motivation for work. However, the ever-increasing importance of big supermarket chains and the high quality standards they have imposed on the global market, are resulting in an increase of the average unit size of greenhouse holdings, which may allow higher quality management during all the production and commercialisation steps.

Technology

LTG predominate in the Mediterranean Basin countries. They have a reduced volume/area ratio, are poorly ventilated and covered by plastic materials that have lower light transmission compared to glass, particularly when dirty and aged. Roof vents are scarcely employed, although its diffusion is increasing. On account of mild winter temperature, heating is generally auxiliary, but high temperature and radiation in summer make cultivation almost impossible without evaporative cooling and forced ventilation. In general, greenhouse crops in the Mediterranean Basin are adapted to non-optimal environment that, on the contrary, is optimised as much as possible in the Northern countries. Compared to Holland, crop yield (Fig. 4) and the use efficiency for both water (Fig. 5) and nutrients (e.g. nitrogen; Fig. 6) are lower in the Mediterranean Basin due to the less advanced growing technologies.

Growers' interest in hydroponics is increasing and these techniques are rapidly expanding in some areas, like Almeria (Fig. 4). Nonetheless, cropping is still based on soil, which very often is characterised by low organic matter, high lime and salinity.

Although the simplicity and the cheap cost of greenhouses are the main features of Mediterranean Basin protected horticulture, many types of structures can be found in these regions, in dependence on local climate and economy. In this regard, two main cases can be discussed.

Almeria (Spain). The original Almeria greenhouse is the Parral, an adaptation of the traditional structure of wood and iron-wire used to support grape vines; it is characterised by a flat roof and perforated plastics (to drain the sporadic rain) and it does not have roof vents. Parral shelter has been largely replaced by symmetric greenhouses (Almeria type), which have small roof slopes and roof vents. The area set up with symmetric or asymmetric multi tunnels is rapidly increasing notwithstanding the investment is twice as high for the Almeria type. One typical feature of Almeria horticulture is the cultivation on *enarenado*. *Enarenado* is an artificial soil that is prepared as follows: on the original (poor) soil, growers apply, in sequence, a layer (30 cm) of clay soil, a 2-cm deposit of manure and a third layer of sand (10 cm). *Enarenado* has many advantages: little management, reduced water loss and salinity problems, and higher temperature during winter. However, *enarenado* requires periodical manure application, which is expensive; moreover, although it resembles artificial substrate culture, it does not allow recirculation of drain water.

Figure 4. Productivity of a few greenhouse crops in some Mediterranean countries and in The Netherlands. Data were provided by different institutions in the selected countries.

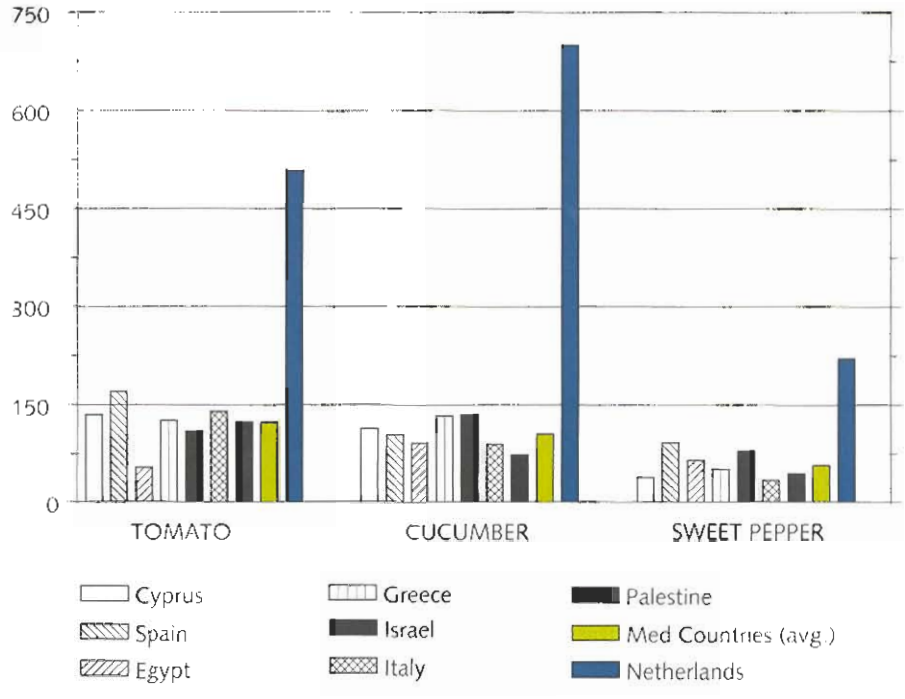


Figure 5. Water use efficiency (WUE) of some greenhouse crops in the Mediterranean countries (soil culture; mean value for Cyprus, Egypt, Greece, Israel, Italy, Spain) and in The Netherlands (soilless culture). Data were provided by different institutions in the selected countries.

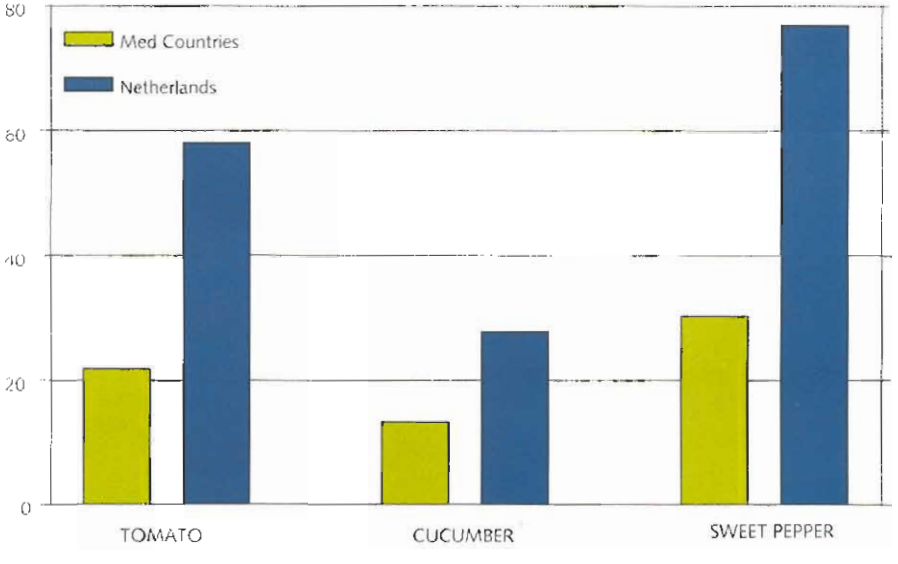
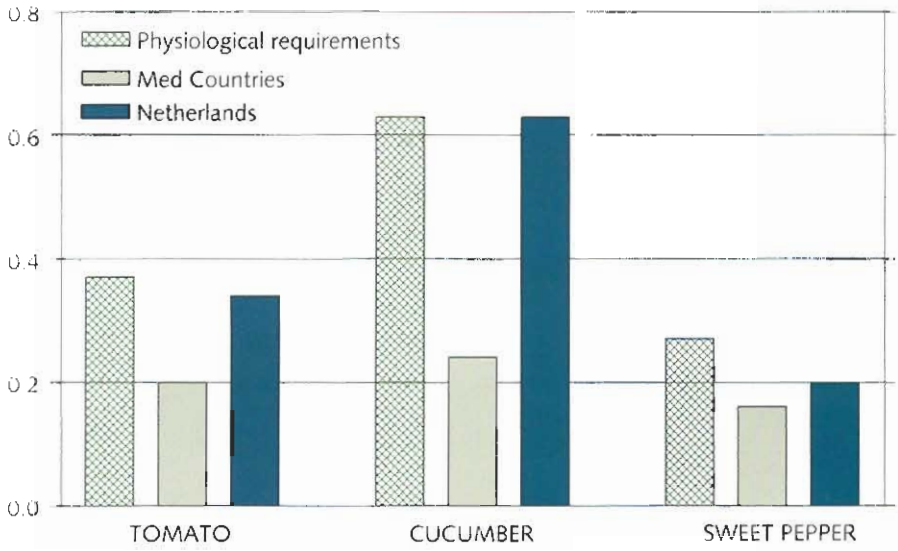
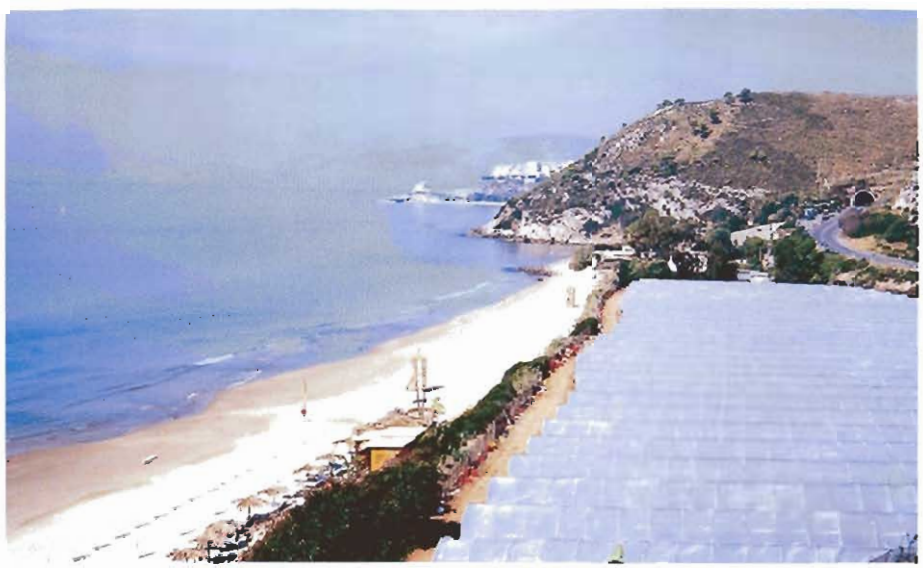


Figure 6. Nitrogen use efficiency of some greenhouse crops in the Mediterranean countries (soil culture; mean value for Cyprus, Egypt, Greece, Israel, Italy, Spain) and in The Netherlands (soilless culture), in comparison with the physiological requirements (according to Tesi, 2001). Data were provided by different institutions in the selected countries.



Italy. Protected cultivation is quite wide spread in Italy on account of its mild climate in winter and the traditional Italian feeling for greenhouses, which appeared first in ancient Rome. Protected crops are scattered all over the country, but the most representative areas are located, moving from the North to the South, in Lombardia, Veneto, Liguria, Tuscany, Lazio, Campania, Sicily and Sardinia. Greenhouses are particularly widespread along the seacoast (Fig. 7). Different types of greenhouses and protection structures can be found ranging from wooden structures covered with plastic film to glasshouses fully equipped for automatic climate control and internal plant transportation. Most greenhouses are covered with plastic films with an emergency heating system, if any. Strawberry, vegetables and some flower crops (e.g. carnation) are usually cultivated in very simple greenhouses, whereas pot plants and propagation material are grown in more sophisticated glasshouses.

Figure 7. Plastic tunnels on the beach (Western Coast of Central Italy). Greenhouse industry often competes with tourism for land and water in the Mediterranean countries (By courtesy of Dr. J.P. Leymonie, New Ag International).



Opportunities

The strong point of Mediterranean Basin protected horticulture is undoubtedly the climate that is characterised by relatively high radiation during fall and winter thanks to the large number of clear days, the mild temperatures during winter and the seasonal stability of the temperature provided by the sea (Fig. 8). For instance, in Sicily more than about 500 hours of sunlight are available during winter, with a daily global radiation of 6-8 MJ m-2 and a mean air temperature of 10-13°C.

The availability and the cost of hand labour, often provided by immigrants from developing countries, also represent an important resource for the sector, which tends to invest more in growing technology (including fertigation) than in greenhouse structure and climatic control. As matter of fact, the adoption of more sophisticated technologies for energy saving, temperature control as well as plant transportation inside the greenhouse have been restricted to the cultivation of pot plants in regions with colder climate (France, Northern Italy).

Limits

Due to the prevalent climate and the current growing technology, the following problems are generally encountered in the Mediterranean Basin:

- lower light transmission (as a result of whitewashing as well) and poor ventilation, which often leads to CO2 depletion, reduced photosynthesis and then crop growth and yield, with an important effect on produce quality as well;
- large fluctuation in temperature, a typical phenomenon in unheated greenhouses in clear-sky regions (sometimes, thermal inversion occurs in winter), is the main reason for variation in productivity during harvesting period and may result in physiological stress of the crop;
- high indoor temperatures typically occur from May to August; this makes almost impossible year-round cultivation, so that the production is generally seasonal with two peaks, in spring to early summer and in autumn (till the Christmas period, if climate is good enough);
- inadequate climate control often results also in high relative humidity which reduces crop transpiration; this may impair leaf cooling on warm days and promote the incidence of nutrient-related physiological disorders, like calcium deficiency (for instance, blossom-end rot of tomatoes and peppers);
- mild winter temperature, high internal humidity, the open structure of shelters, the lack of heating and, in many cases, the irrational management of crop residues facilitate

the proliferation of pests (white flies, thrips, leaf miners) and diseases (grey and black mold, root and stem rot, viruses), and make biological control quite difficult, thus resulting in a large amount of applied biocides;

- the harvest periods for open field and protected crops tend to overlap with consequent decrease of market prices;
- the use of soil, instead of soilless systems, renders the culture dependent on frequent soil disinfection (still based on methyl bromide, principally) and organic fertilisation; moreover, it does not allow the fine tuning of irrigation and fertigation nor the recirculation of drainage water, which are crucial for high crop performance and efficient use of both water and nutrients.

Growing Technologies in Relation to Water Scarcity and Salinisation

Drought and salinisation are the main constraints to the development of the Mediterranean Basin greenhouse industry. Thus the application of drip irrigation together with smart scheduling of water distribution is essential to improve crop water use efficiency.

Much experimental work has been done on the response of greenhouse crops to salinity. Although not all the physiological and biochemical mechanisms underlying the plant's tolerance or sensitivity to salt stress have been clarified, the response of many greenhouse crops to salinity is well established, in terms of both yield and produce quality. Indeed, some practices can be applied to alleviate the negative effects of salinity (Sanchez and Silvertooth, 1996). However, the effectiveness of these cultural practices depends on many factors, such as crop genotype, environmental and cultural conditions. In other words, these practices do not seem completely reliable and compatible with the need of standardised cultivation techniques and constant (predictable) crop yield and produce quality. Genetic manipulation, by means of recombinant DNA technology as well, may provide more salt resistant cultivars of the most important crops; however, the practical application of breeding seems still remote. Finally, poor irrigation water renders almost impossible the use of the recirculating water growing system that is the most effective technology to reduce the environmental impact of greenhouse crops.

Therefore, it seems that the use of treated wastewater and seawater (and rain water as well, where possible), coupled with the application of water-saving technologies (mulching, drip irrigation, smart scheduling of water supply, closed-loop hydroponics), might be an effective strategy to solve the problems related to water. Desalinised water, of course, costs much more than raw water; however, compared to other agricultural sectors, pro-

Figure 8. Monthly means of the relevant climatic factors in three different regions: Almeria (South-East Spain), Versilia (Tuscany, Central Italy) and Wageningen (Netherlands). The most important effects of external climate on indoor conditioning are shown (after Von Zabeltitz, 1999). [Source: Italy, ARSIA-Regione Toscana; Almeria and Netherlands, Costa and Heuvelink, 2000].

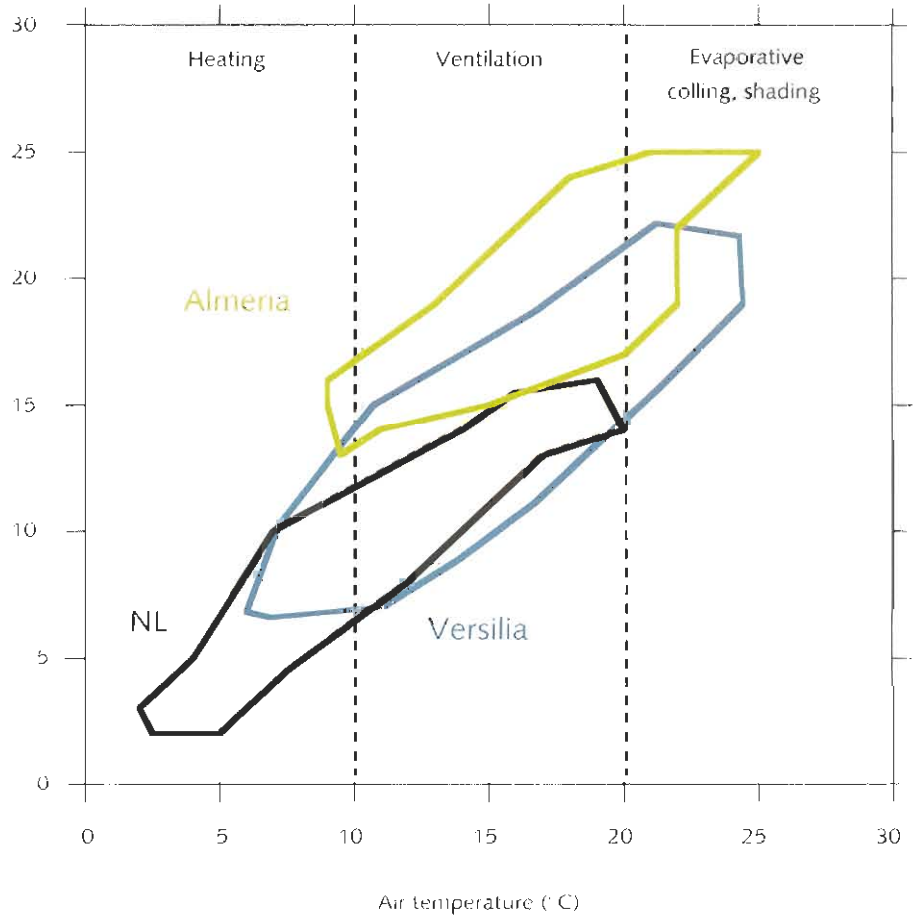


Figure 9. Seawater desalinisation plant in Carboneras, Almeria (Spain).

tected horticulture is much less affected by the cost of irrigation water due to high marginal price (Stanghellini et al., 2003). Undoubtedly, greenhouse growers fear the scarcity of water much more than its cost. Last but not least, the availability of high quality (i.e. low salinity) water may increase the production flexibility, in that growers do not have any limitation when crop and cultivar have to be selected for a production plan. And flexibility is crucial for the commercial competitiveness of the sector.

A seawater desalinisation plant has been recently established in Carboneras (Almeria) to exploit seawater for urban use and irrigation (Fig. 9). The potential of the plant, which is based on reverse osmosis, is about 120,000 cubic meters per day (nearly 44 million of cubic meters per year) of desalinised water, which may be distributed to about 5,000 hectares of horticultural crops at a price of around 0.8 /m3. Desaladora de Carboneras, the largest in Europe and second in the world, may provide data for policy makers in many Mediterranean Basin countries.

Marketing Policy

The future development and success of Mediterranean Basin protected horticulture does not hinge on growing technology only. A comprehensive marketing policy must be implemented in order to reduce transportation costs, supply the market, in particular the big supermarket chains that are now prevalent in the Western Europe, with labelled and quality-certified products, and stabilise their prices. It is becoming a common practice that big retail groups include in the contract with large producer organisations detailed growing protocols for the environmentally sound production of healthy commodities. Therefore, there is the need for grouping growers into large (co-operative) commercial organisations, in order to improve their ability to get a satisfactory commerce, including a remunerative price of their products. The commercialisation of innovative products may support the growth of the sector. For instance, fresh-cut (also named ready-to-use or minimally-processed) fruits and vegetables may represent a commercially valuable produce.

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