SUSTAINABLE GREENHOUSE PRODUCTION IN MEDITERRANEAN CLIMATE: A CASE STUDY IN ITALY

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Abstract

Thanks to the introduction of plastic materials, in the last decade, greenhouse production has widely spread both in the Mediterranean area and in Italy. After a short review of the present situation of the Italian greenhouse sector, problems connected with the sustainability of this activity, especially the technical construction aspects and the environmental effects, are discussed and technical innovation process of Italian greenhouse are proposed.
As a matter of fact, the main causes of unfavourable effects produced by greenhouses on the environment are: the disposal of construction materials, the use of fertilizers and pesticides, the withdrawal of irrigation water, the emission of gases and contaminants, the visual impact.
Therefore building and equipment engineering solutions are proposed, like soilless cultivation with closed system at root zone, in order to promote a sustainable development of greenhouse cultivations through a systems analysis, pursuing the reduction of quality and quantity of contaminants and the recycling of wastes.

Résumé

Grace à l'introduction des matériaux plastiques, pendant la dernière décennie, la production en serre s'est grandement répandue dans la région méditerranéenne et en Italie en particulier. Après un bref aperçu de la situation actuelle du secteur des serres en Italie, on discute des problèmes liés à la durabilité de cette activité, notamment des aspects techniques de construction et des retombées environnementales, en proposant un processus d'innovation technique des serres en Italie.
Parmi les causes principales des effets défavorables produits par les serres sur l'environnement on cite: la décharge des matériaux de construction, l'emploi d'engrais et de pesticides, le prélèvement de l'eau d'irrigation, l'émission de gaz et de contaminants, l'impact visuel.
L'on propose ainsi des solutions de construction et d'équipements telle que la culture sans sol avec système clos dans la zone racinaire, afin de promovoir un développement durable de la culture en serre à travers l'analyse des systèmes, visant à réduire la qualité et la quantité des contaminants et au recyclage des déchets.

Greenhouse crops are one of the most innovatory examples of modern agriculture and it is envisageable for them to expand more and more in future, especially in areas with unfavourable climatic conditions. They are one of the highest man-made forms of agricultural activity, because of the intense technological and bio-agronomic inputs in confined portions of the agricultural environment.

As a matter of fact greenhouses are a means to grow crops by overcoming adverse weather conditions; they exploit solar radiation to condition indoor micro-climatic parameters, also with the use of equipments, aimed at optimizing crop production in areas or in periods of the year not suitable for open field cultivation. The first examples of off-season vegetable cultivation go back to Plinius who, in 77 a.C., describes cucumber cultivation in special baskets covered with transparent talc or steatite sheets to enrich the table of Tiberius all over the year (Stanghellini, 1994). After a slow evolution process started in Europe in the XVI century, a strong boost to the diffusion of greenhouse crops was given, starting from the 60s' in Italy and in other countries, thanks to the introduction of plastic cladding materials; in 1993, they covered 220,000 ha worldwide, whereas small inaccessible tunnels and mulched areas (**figure 1**) amounted to 250,000 ha and 4,000,000 ha, respectively (Garnaud, 1994).

At present, the greenhouse covered area in Italy amounts to more than 25,000 ha, in addition to 20,000 ha of small tunnels and about 7,000 ha of seasonally protected fruit crops. With reference to the data of 1992 (ISTAT, 1992), from an economic point of view, greenhouse vegetable crops, although covering a surface equal to 0.15 % of the A.A. (Agricultural Area) contribute by more than 2,000 billion It. liras per year (1.3 billion

Figure 1 - Field with floating mulch and plastic greenhouse.

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US$) to almost 4% of the domestic agricultural g.m.o. (gross marketable output) and to about 20% of the whole vegetable sector g.m.o.
In the flower and ornamental plant sector, characterized by a g.m.o. of 2,300 billion It. liras (1.5 billion US$), more than half of the total flower-grown area is under greenhouses, and almost all ornamental plant production comes from protected cultivations.At the moment the Italian greenhouse and tunnel manufacturing firms, including both industrial and artisan firms, are about 120, with a total yearly turnover of about 150 billion It. liras (100 million US$), and there are approximately 20,000 greenhouse growers.
Greenhouses are widespread all over Italy with a greater concentration, about 60% of the total, in southern regions, where the so-called Mediterranean greenhouse (Castilla, 1994; Stanghellini, 1994) has got established; it consists of low cost structures, with plastic film covering and no winter heating, exclusively based on the use of solar radiation to increase the indoor temperature: «cold greenhouses» concern approximately 70% of the total protected surface, whereas the remaining 30% concerns the ones already provided with equipments for indoor microclimatic control (Tesi, 1991). Consistently with the previous data, 90% of protected surface is covered with plastic material, especially flexible plastic single sheet laminates of 0.14 ÷ 0.18 mm in thickness, or double sheets with the inner layer of 0.02 ÷ 0.05 mm, or more rarely, rigid laminates; only 10% of the area has a transparent glass covering. About the crop destination 87% of the greenhouse covered areas are used for vegetables and 13% to grow flowers or pot plants.
As for the types of greenhouses, two major lines are followed in Italy:
– increase and enlargement of low technological input greenhouses, for vegetables and low-temperature flower crops, of low investment and low running costs and fairly good energy efficiency (**figure 2**). They consist of lightweight steel, or timber and concrete structures, covered with plastic films, without heating system or with simple supplementary heating equipment, aimed at the best use of solar radiation, situated in vegetable prone areas having more favourable climatic conditions;
– expansion and evolution of greenhouses with high technological input for flower growing, ornamental plants and nursery, with steel structure, provided with equipments for the control and regulation of indoor microclimatic parameters (**figure 3**), aimed at improving the quality of products, to curb energy consumption and reduce labour time. Investment costs of such greenhouses can be 10 to 20 times higher than the abovesaid cold greenhouses for vegetable crops.

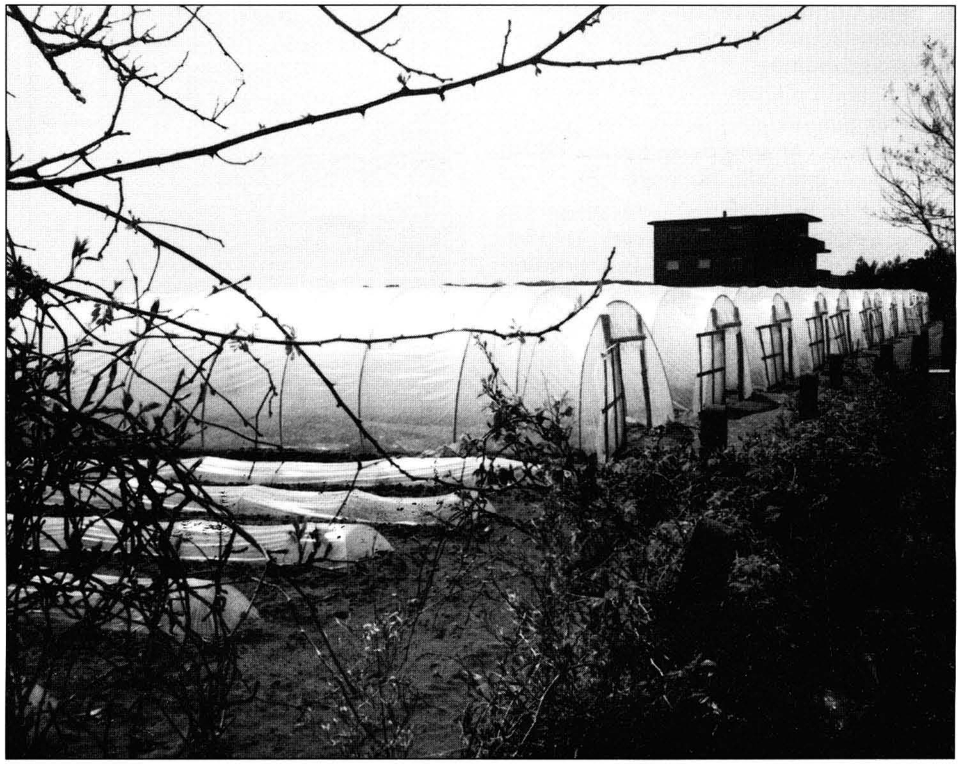

Figure 2 - Cold greenhouse tunnels with plastic film covering for vegetable production.

Figure 3 - Heated greenhouse with glass covering for pot plants production.

Present problems of sustainability in greenhouse cultivation in Italy

Considering the greenhouse system as a whole (**figure 4**), the problems the Italian greenhouse sector is facing at present can be summarized as follows:
- economic-marketing;
- bio-agronomic;
- technical-building;
- environmental.

The purpose of studies and research on protected cultivations must be now oriented to the development of greenhouse systems analysis in order to combine design, management and production models of greenhouses.

Economic marketing and bio-agronomic aspects

The domestic vegetable-flower-nursery greenhouse production is progressively reducing its national and international market shares due to the competition by other countries, especially those of the Mediterranean region, which can benefit from better climatic conditions and lower labour costs. Difficulties are also related to the lack of coordination between the production cycle and marketing, the distribution being by now characterized by the big sales chains of agro-food products.
Three hundred domestic fruit and vegetable markets are too many to guarantee an optimal and profitable wholesale distribution. By a sounder ratio between growers, market and distribution network, intermediate costs could be curbed and quality and economic production standards could be improved.
Moreover, an attempt could be made for a strategy aimed at producing typical flower and vegetable protected crops in Italy, by relating it to our artistic and naturalistic resources, in the case of flowers, and to our gastronomic tradition in the case of vegetables. Also a modern marketing strategy (Tognoni & Serra, 1994) has to be pursued for packaging, transportation and preservation in order to offer a product with optimal organoleptic properties, i.e. «fresh, nice, good, healthy and uniform».
Further studies on bio-agronomic aspects can cover: the quality of products, considering also the different micro-climatic conditions with respect to open field crops (Tognoni & Serra, 1994); the new plant protection regulations introduced in the recent national and EU rules; the strategies of plant breeding for resistance to diseases and to extreme temperature conditions (Saccardo & Sonnino, 1988); the biological and integrated control systems, like the use of predatory insects and useful parasites reared in bio-factories (Benuzzi, 1988; Cirio, 1988).

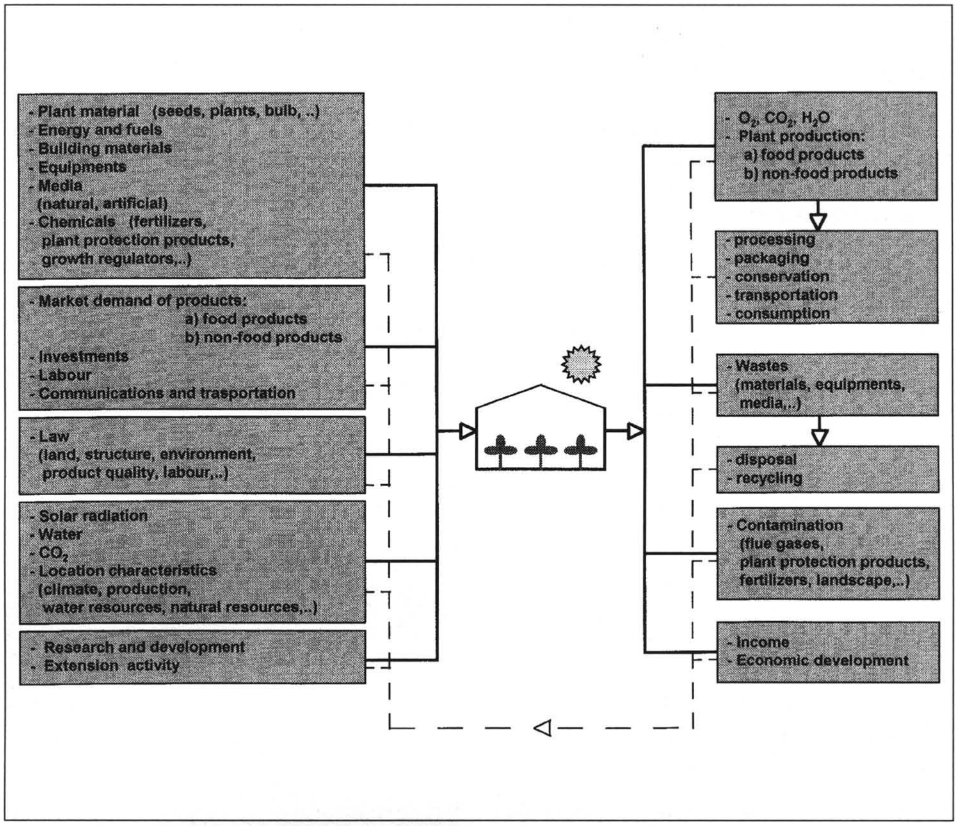

Figure 4 - Flow chart of inputs and outputs of the greenhouse system.

Technical and constructive aspects

The absence of specific regulations for greenhouses, in terms of land, structures and equipments, is an element of uncertainty and restriction on the development of the Italian greenhouse cultivation which is connected with emerging problems related to the influence of the agro-ecosystem and on the quality of food products.
At present, regulations on greenhouses in Italy are extremely confused, controversial and heterogenous.
Land planning regulations on greenhouses have no national law (Bianchi & Sancilio, 1992); they are regulated at the regional level – even rather differently only in seven regions out of twenty – and at the municipal level by restrictions discretionarily imposed by the local technical authorities. The only nationwide applicable limit is, at present, the one relative to zones protected by the Ministry of Cultural and Environmental Resources, which is inadequate for building structures which cover, as a total, more than 250 Km^2.
The solution should consist in reducing the restriction scheme and «zoning» rural land, at a scale much larger than that of each single municipality, based on criteria of environmental impact and loads, of production and climatic suitability of the areas, of proximity to the markets, of availability of communication and transportation systems, as well as of the preservation of resources and landscape.
The building rules for the design and construction of metal structures for greenhouses go back to 1971 (UNI 6781-71) and, with partial adjustments, they still are the only reference for the designer although not being legally binding. According to the present law, the designer should refer to the provisions of law on buildings, whose building characteristics and uses are quite different from those of greenhouses. Within the countries of the European Union, a Technical Committee, CEN TC 284, has been recently established for the purpose of establishing a structural European standard for greenhouses, which take into account the specific production purposes of the latter and be based on probability criteria for the evaluation of loads:

the introduction of these standards in Italy will be a valid instrument for a sounder operation of the whole sector.
As for the regulations on equipments and safety at work, numerous national provisions of law are available on thermal stations, on fire-safety, on electrical plants and on health and safety at work which would require a more comprehensive and specific view of greenhouses.
In addition to the regulatory aspects, the productivity and quality of greenhouse cultivation in Italy are strongly conditioned by the technological standards which characterize the construction of greenhouses.
In fact, in the lower technological input greenhouses, the following is often observed:
– excessive extreme variations in indoor minimum night air temperatures and maximum day temperatures, which cause thermal stresses to crops;
– excessive indoor air temperatures during summer season, which limit the utilization of the greenhouse all the year round;
– excessive indoor relative humidity, especially at night, which favour the onset of diseases;
– absence of temperature control of the cultivation medium and then of the rooting system;
– insufficient ventilation rate with indoor daytime depletion of CO_2 concentration in the air;
– condensation water formation at the internal face of the transparent covering, especially if made of plastic film, with water dropping on the canopy;
– insufficient control of solar radiation;
– high thermal losses, especially by irradiation at night;
– high irrigation water and fertilizers use;
– intense and expensive treatments with plant protection products for the control of pathogens.
It is then desirable to start a constructive process of technological innovation in the construction, engineering and management (**figure 5**), in order to achieve:
– an increase in the control standard of indoor microclimate through systems of heating, cooling, ventilation, shadowing, thermal screens and double covering;
– a wider diffusion of covering materials more appropriate to thermal and light requirements of the species grown and capable of offering a good mechanical resistance to external stresses and ageing;

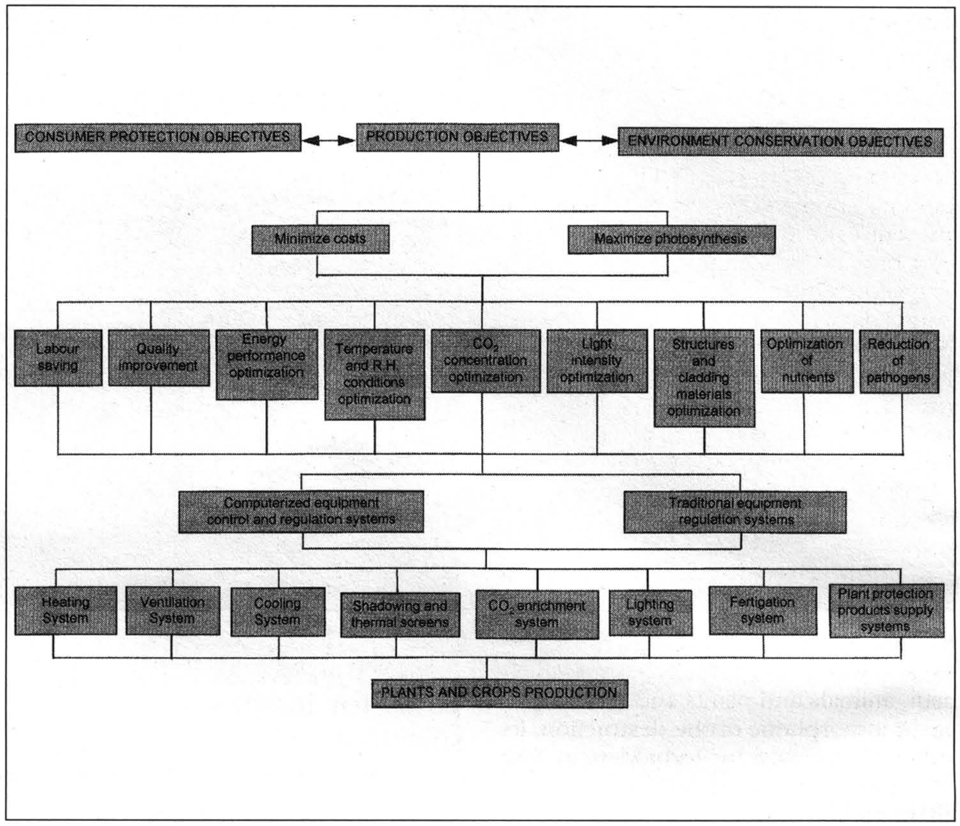

***Figure 5** - Production process plan of protected cultivations.*

– the installation of highly efficient irrigation systems, like the low discharge systems, possibly integrated with fertigation plants;
– wide recourse to soilless culture (Olympios, 1993), with recirculating nutrient solution, which uses low cost and locally available artificial media.

Environmental effects of greenhouse production

The limited land area covered with greenhouses could lead to underestimate their environmental impact. But, from a more careful analysis, both the influence of protected cultivation on the agro-ecosystem and the pollution caused in the different environmental sectors, also because of the high number of greenhouses in some concerned geographic districts, do come out. Also of importance are the effects of safety at work, during the application of chemical treatments, and the quality of food products for the consumer's health.
The main causes of the general unfavourable effects produced by greenhouses on environment (**figure 4**) can be summarized as:
– the disposal of plastic materials due to the renewal of transparent covering and mulching (Scarascia et al., 1994). At present, the total yearly amount of agricultural plastic wastes in Italy equals about 100,000 t; such wastes, and plastic films in particular, are mainly disposed into unauthorized dumping sites, in water streams or indiscriminately burnt (**figure 6**). The improper management of plastic wastes produces unfavourable effects on the major environmental components, i.e., soil, water and air;
– the massive supply of plant protection products and fertilizers. The special indoor temperature and humidity conditions which favour the development of pathogens, the highly intensive use of soil and the high value of crops grown, often lead to an indiscriminate use of chemicals (Cirio, 1988) which cause toxic and noxious residue accumulations in the soil, in ground waters and in the edible organs of the plant with the subsequent uptake by consumers. In fact, pesticides supply in greenhouse can be as high as 400 kg/ha year, whereas the total methylbromide consumption has reached 5.370 t/year, mostly used to sterilize the soil of greenhouses by fumigation (Basile et al., 1987) with high hazards for operators, against a total European consumption of 12,000 t/year. As methyl bromide is extremely toxic to

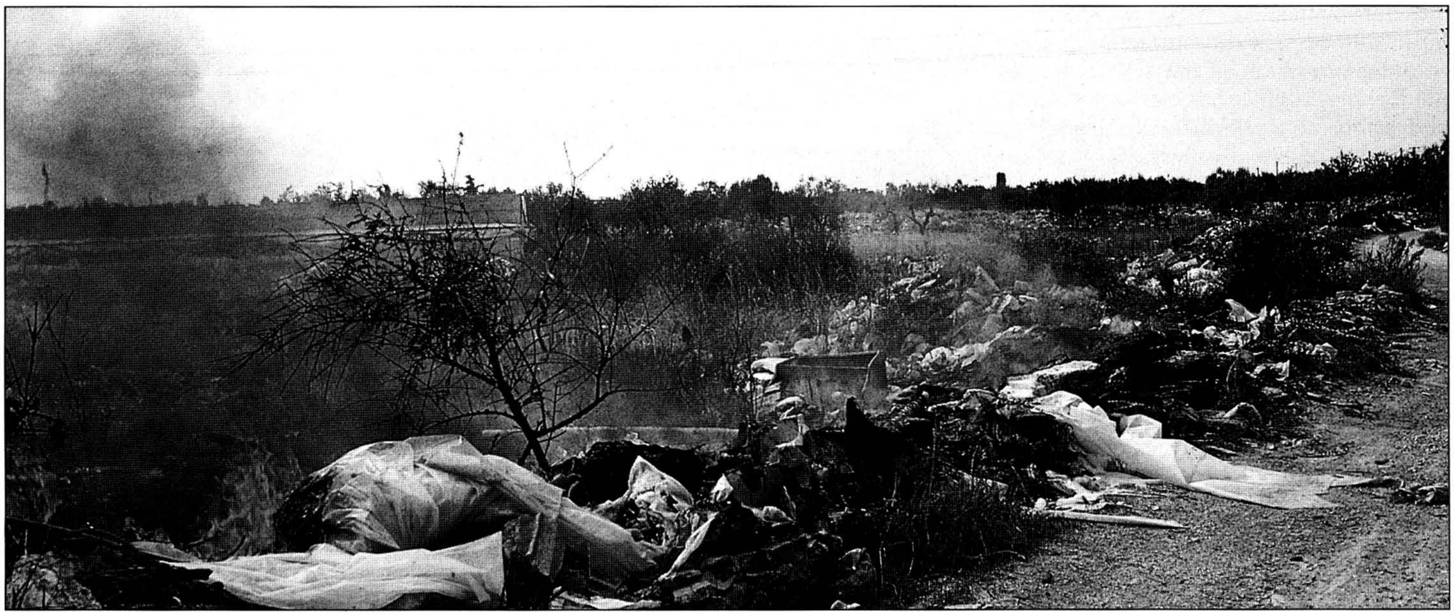

Figure 6 - Uncontrolled burning of greenhouse plastic film covering materials.

man, animals and plants and contributes to the atmospheric ozone destruction, its use will possibly be forbidden in few years time. Also the excessive use of fertilizers results in the supply of chemical compounds, especially nitrogen, phosphorus and heavy metal ions which can build up in water bodies, in the soils and in the plants with noxious effects on man;

– intense withdrawl of water for irrigation purposes, due to the notable water requirements ranging from 1,000 to 1500 l/m^2, which excessively impoverishes groundwaters with the subsequent drawdown of the piezometric level and an increase in salinity, especially in coastal aquifers. This causes alkalinization and the loss of soil fertility with dramatic effects on productivity of greenhouse crops;

– flue gases and emission of suspended particles from the thermal equipments of greenhouses equipped with winter heating system, with energy requirements amounting, in Italy, to about 10,000,000 GJ/year (Renagri, 1990);

– changes in landscape and land morphology due both to the visual impact of greenhouses, characterized by extended areas and by the reflectance of the covering material, and to the changes in the orography of the sites in order to obtain the most adequate position of soils, either flat or terraced. In this connection, the coastal zones and the turism prone areas are particularly vulnerable and subject to detrimental and permanent visual changes with «pollution of the horizon».

Tools for increasing the sustainability of greenhouse cultivations

The instruments, the methods and the interventions for the control and limitation of the said negative environmental impacts and for an environmental friendly development of greenhouse cultivation can be identified by pursuing two objectives:

– to reduce the quantity and control the quality of contaminants and wastes produced;

– to control, convey, treat and recycle wastes.

Sustainability can be also defined by means of entropy: a production is sustainable when it produces minimum increase of entropy. For greenhouse production the purpose consists in the use of renewable energy and recycling of construction materials, in order to have an entropy change tending to zero.

In addition to the required bio-agronomic interventions, the building and equipment engineering solutions could be:

– the setting up, through adequate control measures and incentives to growers, of a landwide network of collection and storage centers of post-consumption plastics (Scarascia et al., 1994) and of artificial media for the subsequent treatment and re-use of wastes as secondary raw material, or for energy regeneration by incineration and by exploiting heat wastes for greenhouse heating;

– the use of energy saving types of covering: in additon to thermal sheets and low emissivity glass, the adoption of the double covering layer (Baytorun, 1993) or thermal screens produce an energy saving respectively equal to 20÷40% and to 30÷50% against a reduction of indoor luminosity respectively of 10÷20% and 5÷10%. Also in the case of cold greenhouses such a solution is recommended in that it enables to increase indoor temperature by 2÷4°C, avoiding the phenomena of night temperature inversion in the greenhouses with a single plastic sheet covering;

– the use of alternative energy sources like unconventional fuels, geothermal energy in geographic areas where such resource is available (Popovski, 1988), industrial heat wastes (O' Flaherty, 1988), the biogas produced from agricultural biomasses or from municipal solid wastes dumping sites (Scarascia, 1992);

– the installation of closely-meshed antinsects virus-carrying nets, or bionets, at the ventilation openings in order to keep disease-carrying insects out (Scarascia, 1992);

– partial sterilization of the agricultural soil, in the case of ground-based crops, through solarization performed by exploiting the intense solar radiation in summer through soil mulching with transparent plastic sheets (Scarascia, 1992);

– the adoption of innovatory irrigation systems adequate to the needs of protected cultivations: irrigation requirements in greenhouses can become as low as 20÷50% with respect to open field, the unit yield being equal, through a better crop productivity in protected environment and to an approximately 25÷40% reduction in evapotranspiration (Abou-Hadid, 1993; Caliandro & Cucci, 1976; Stanghellini, 1994). By ensuring an irrigation efficiency as high as 90%, the low discharge systems can result in considerable savings. Also the use of rainfall water for irrigation should be increased by conveying it through the greenhouse gutters into storage reservoirs;

– growing natural vegetation barriers serving as screens can reduce, together with a careful localization of greenhouses in high value landscape areas, the visual impact on landscape;

– the adoption of soilless cultivations, such as hydroponics, which break the continuity between the confined environment and the underlying soil to prevent the contamination of the latter. Soilless cultures are characterized by the absence of natural soil, replaced by substrates made with artificial media of different kind, or plant support structures (Olympios, 1993; Leoni et al., 1994). The rooting apparatus is nourished by the circulating nutrient solution, or the spraying of the latter which has to contain all the elements required for plant development. At present, soilless culture can be considered to be the best choice for the introduction of closed systems at root zone, with recirculating nutrient solution, in order to eliminate or reduce the release of contaminants to the environment (van Os, 1994). For this purpose, the fertigation system should be equipped with control instruments for the pH, electrical conductivity and nutrient levels and subsequent integration and sterilization of the solution. The soilless culture technique is finally extending also in Italy, under its different forms: on benches with ebb and flow system, on capillary mats, in small channels with NFT, in bags with artificial media and drip irrigation system, as the so-called «spaghetti tubes» system. Advantages are many: very high yield efficiency; control over the supply of water, of nutrients and of plant protection products and their saving; absence of soil sterilization practices; uniform and controlled plant growth; product quality improvement; clean working environment; labour saving; possibility of using unproductive soils or areas with no arable land; optimal integration with automatized microclimate control and regulation systems of the equipments (Scarascia et al., 1993) and the nutrient solution. The diffusion of this technique is especially hampered by the high specialization required and the high investment and running costs which, as from all the above, could be curbed thanks to the savings achievable and the production of healtier and more marketable products. On the other hand, the environmental damages caused by the traditional cultivation methods involve costs for the community and, possibly, ecological taxes imposed on the polluting firms.

Conclusions

For the Italian greenhouse cultivation to become part of sustainable agricultural activity and then a competitive, environmental and consumer friendly one, efforts should be made to curb consumption of non-renewable energy resources, to reduce pollutant release, to curb the use of chemicals, to increase the technological standard of structures and improve the management of micro-climate and irrigation and extend the use of soilless culture with closed system at root zone.

The modern cultivation methods need an increasing use of computer aid in order to have in the greenhouse a climatic and cropping management interacting with the economic-marketing management, following a forecast approach to crop scheduling based on periodically up-dated data files on the climatic, production and market pattern. The most advanced greenhouses will serve in future as plant production factories and will be provided with heating systems, both for the indoor air and for the cultivation substrate, with cooling, ventilation, lighting, CO_2 enrichment, fertigation, plant protection products supply equipments, shadowing and thermal screens, integrated control systems, handling and management of cropping operations, tissue culture and cold stores, globally controlled by computerized systems.

The control can be made by plant monitoring methods through image analysis which simulate the action of the greenhouse grower in evaluating the physiological processes and the plant growth stages: this would thus lead to the so-called «reading plants' face technique». As a consequence labour conditions can be improved by a better quality of workplace and a more attractive employment. Within all those terms, design models, developed by means of greenhouse simulation models and construction materials life cycle analysis, are a tool for a design founded on a systems analysis. An even farther future prospect could be the projects and experiences for the realization of plant growing structures within orbiting space stations: the implementation of «space farming», which will benefit from the results of the research works made in the greenhouse sector, will be the highest evolution stage of engineering knowledge applied to the design of confined environments for plant growing. ●

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