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OVERVIEW OF SOILLESS CULTURE: ADVANTAGES, CONSTRAINTS AND PERSPECTIVES FOR ITS USE IN MEDITERRANEAN COUNTRIES

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Abstract: Considerable progress has been made recently in the development of media and economically viable soilless systems and a number of growers in different Mediterranean countries are using soilless culture commercially the extend of which varies, according to the level of education of the growers, the existing greenhouses' facilities and their level of organization. It is well known that soilless culture offers an alternative to soil culture when serious soil and water problems (i.e., soilborn pests, soil and water salinity, chemical residues in soil, water salinity, lack of fertile soil, water shortage, etc.), create difficulties in traditional soil-based production. The main advantages of soilless culture are the most accurate control over the supply of water, nutrients, pH, root temperature, etc., increase productivity due to easier and more accurate control of production factors, reduction of labour requirement, no need for soil sterilization, more crops per year, etc. On the other hand there are disadvantages like the higher initial capital investment for the construction and maintenance of the soilless setup, the risk of disease infections mainly in the recirculating (close) systems, occasionally the increase of labour requirement and the need for higher standard of management and skill compared to crops growing in soil. The margin of error in fertilizing and watering is reduced with soilless culture. Also of importance is the subject of environmental (soil & water) pollution by waste nutrients with the open systems which in less developed countries are more popular because they are easier to handle. Expansion of soilless culture in various Mediterranean countries at present and the years to come will depend in one hand on existing knowledge level of the growers, the organization and background facilities available as well as the degree of education and adoption of the new technological developments on soilless culture. On the other hand, the speed of expansion in Mediterranean countries is greatly depended on the development of technically simple, reliable, with low cost, soilless systems, using if possible local low cost materials as substrates or pure hydroponic systems with the simplest automated systems which can be installed in structures of low investment, requiring low management techniques, in order to attract the attention and interest of the growers.

INTRODUCTION

The origins of soilless culture go back at least to the 17th century when, in 1666, Boyle attempted to grow plants in "vials containing nothing but water", and reported that one species (spearmint, *Raphanus aquatica*) survived for nine months. However, it was not until the 19th century that Liebig (1803-73) and Knop and Sachs (around 1859) initiated the systematic study of plant nutrition (Cooper, 1979).

The first person to promote the commercial potential of liquid culture was Gericke (1929). The plants were planted in a layer of sand which was supported on the surface of the solution by netting and canvas through which the roots could pass into the liquid phase. Originally Gericke (1929) defined his method as "aquaculture". However, since this term was already in use for the culture of aquatic plants and animals, other terms were quickly introduced, namely "water culture" and "solution culture". Finally, the term "hydroponics" was proposed by Setchell, based on the Greek hydro (water) and ponos (labour).

Gericke's method however, has a main disadvantage, the lack of aeration. One way of overcoming the difficulties of oxygenation was the development of nutrient film (NFT) and circulating nutrient solutions. Another way was the use of aggregate substrates in which although all the nutrients are supplied to the plant with the water, there is nevertheless an inert rooting medium which provides both support for the plant and a means of oxygenation / aeration of the roots (Figure 1). Although there has frequently been dispute concerning the precise definition of what is and what is not a soilless (or hydroponic) medium -for example, organic substrates such as peat may contribute to the nutrient status of the system- the classification proposed by the FAO Report (1990) is widely accepted today.

Soilless culture has often been called **hydroponics**, although **nutri-culture** is a more accurate definition of certain types.

The methods of growing plants without soil fall into two general categories:

(a) **Liquid culture** (true hydroponics), where the nutrient solution is recirculated after re-aeration and adjustment of the pH and nutrient levels (e.g. NFT) and

(b) **Aggregate culture**, where the nutrient solution is supplied to plants via an irrigation system through the media, and excess solution is allowed to run to waste or the solution is recirculated (e.g. rockwool, pumice, perlite, sand culture, gravel culture etc.).

Table 1 - SOILLESS CULTIVATIONS SYSTEMS HYDROPONICS

SOLUTION CULTURE ("TRUE HYDROPONICS")	AGGREGATE SYSTEMS		
	INORGANIC MEDIA ("HYDROPONIC")		ORGANIC MEDIA
	NATURAL MEDIA	SYNTHETIC MEDIA	
1. STATIC SOLUTIONS	1. SAND	1. FOAM MATS (PUR)	1. SAWDUST
2. CIRCULATING SOLUTIONS (NFT)	2. GRAVEL	(POLYURETHANE)	2. BARK
	3. ROCKWOOL	2. "OASIS" (PLASTIC FOAM)	3. WOOD CHIPS
3. AEROPONICS	4. GLASSWOOL	3. HYDROGEL	4. PEAT
	5. PERLITE		5. FLEECE
	6. VERMICULITE		6. MARC
	7. PUMICE		7. COCOSOIL
	8. EXPANDED CLAY		
	9. ZEOLITE		
	10. VOLCANIC TUFF		
	11. SEPIOLITE		

In Northern West Europe over the last decades the application of hydroponic and substrate cultures has increased considerable as a result of the non suitable soil conditions and monocultures (Table 2). The initial aim was the higher yields and a better control of the root growing factors and nutrition and more recently to avoid the pollution of the environment by waste fertilizers and pesticides. In many Mediterranean Countries with less agricultural development, the application of soilless culture for crop production is still limited (Table 3).

To satisfy the initial aim the first soilless systems adopted commercially were the open ones. Excess nutrient solutions flows directly into the soil surface and underground water polluting the

environment. In places with large areas under greenhouses cultivation in a relatively small area, like Holland, because of the pollution problem the government was forced to vote a legislation that by the year 2000 nearly all the glasshouse area should be based on soilless systems that is separate from the subsoil. Also by 2000 the use of pesticides will decrease to 65% of the level of 1988 and 50% higher energy efficiency compared to 1980 (Ammerlaan, 1994), Table 2. Recent regulations in Germany, do not permit anymore new installations of open systems (Schröder, 1994).

Table 2. Glasshouse production in the Netherlands in 1992, area of soilless culture and targets of Dutch government for the years 1994 and 2000

Glasshouse production in the Netherlands in 1992.						
Vegetables :			4590 ha			
Cut flowers & Pot plants :			5344 ha			
Area (ha and %) of soilless culture for vegetable and flower crops in the Netherlands.						
Year	Vegetables		Cut flowers		Pot plants	
	ha	%	ha	%	ha	%
1985	1139	26	278	9	449	89
1990	2735	61	479	19	983	100
1991	2942	65	566	21	1049	100
1992	3290	72	652	23	1081	100
Dutch government targets in percentage area (%)						
Year	1994				2000	
	Vegetables		Flowers			
Independent of soil			80	30	100	
Closed systems (recirculation)			30	30	100	

Source: Ammerlaan, 1994.

Table 3. Area of soilless culture in various mediterranean countries and some other countries of the world

COUNTRY	AREA (HA)			REMARKS
	Vegetables	Ornamentals	Total	
France	900	73	973	(Rockwool or Glasswool 720), (Pozzodona 173), (NFT 80) Olympios 1994
Spain			1000	Sand bags, Rockwool and Perlite Castilla (pers. com.)
Italy	30	6.8	36.8	Rockwool, Pozzolane, NFT, Perlite
Greece	30	3	33	(Rockwool 26), (Perlite 3), (NFT 3), (Cocosoil 1) 1996
Egypt	15	100	115	Peat, (NFT 3), (Sand 6), (Vermiculite + Peat 100), Rockwool Abou-Hadid (pers. com.) 1996
Morocco	21.5	6	27.5	Gravel, Sand, Pozzolane
Tunisia	6	4	10	Sand, Rockwool
Germany	60	-	60	Mainly Rockwool Schröder, 1994
Belgium			600	Rockwool, PUR,
Japan			700	(NFT 102), (Deepflow 278), (Rockwool 256), (Gravel 26)

Furthermore, the Ministry of Environment in Holland set guidelines stating that the creation of waste and the consumption of raw materials must be prevented. New closed soilless systems should not create new wastes. Therefore, the sustainability of substrates and materials used in closed systems is very important. So, materials, which can be recycled after their use, are preferred. Various studies have shown that water and fertilizer consumption and hence waste of fertilizers into the environment could be substantially reduced (Van Os, 1994).

ADVANTAGES AND CONSTRAINTS OF SOILLESS CULTURES

Advantages of soilless cultures

A considerable amount of research work was published in recent years stating the advantages of soilless culture. The advantages to be mention in this paper does not necessarily applied to all soilless systems and all substrates employed, taking into account the variation between the systems and the degree of sophistication applied to each one of them.

1-Increase productivity

The matter of increased yields with the application of soilless culture should be examined carefully. It is true that precise control of nutrition to the plants grown in soilless cultures will result in higher yields and quality, but this does not necessarily mean that yields from the best cultures in soil are much inferior (Stoughton, 1969). Nevertheless it is difficult to believe that the fast increase in area in soilless culture in the Netherlands and other European countries would have occurred unless commercial growers were confident of some yield increase to help offset the additional cost of soilless culture (Van Os, 1982).

It is of course understandable that if there are soil problems, (i.e. poor soil, saline soil, toxicities in soil, etc.), then soilless culture will produce much better crops. Many reports were published during the last 15 years presenting results on comparison of soilless methods and soil. Most of them show advantages towards the soilless systems, but this was usually been due to a combination of factors such as reduction of labor, higher yields and the greater uniformity of quality due to the more uniform conditions of growth. It must be mentioned however, that in many experiments the management of crops in the soil is not controlled properly.

2-Control of plant nutrition

The accurate control of plant nutrition compared to soil cultures, is also one of the most important advantages of soilless culture. This can be seen from:

- The point of view of the controlled concentrations which can be applied to the various crops, various environments, stage of plant growth, etc. Also harmful elements to plants, above certain concentrations can be kept within safe concentrations (i.e. Mn, B, Zn, Cu, Pb, etc.)
- Another important advantage related to plant nutrition in soilless culture, is the uniformity with which nutrition elements can be supplied to the substrate. This is particularly true with water culture and the more sophisticated systems and less true for the aggregate cultures, especially the most simple ones using surface drip irrigation systems (sand culture, etc.).
- When using water cultures or aggregate cultures with inert substrates the level of nutrients supplied to the new crops are those chosen by the manager. This is not the case with soil cultures where in many cases excess nutrient levels in the soil from the previous crops produce salinity.

- Another advantage of the soilless culture related to plant nutrition is the ability to control the pH and the E.C. of the nutrient solution according to the requirement of the crop and the environmental conditions. Similar control in soil cultures is very difficult and expensive.

3-Water economy and control

Water is by all means the most important factor for crop production. Protected crops require large amounts of water due to exclusion of rainfall when crop production is required in hot, arid regions of the world, water is like to be a limiting factor not only of availability but also of quality and cost.

The advantage of soilless culture related to the ease of irrigation applies mainly to certain soilless systems, such as NFT and other true hydroponic systems (where the plants have their roots immersed into the nutrient solution) and to sub-irrigated substrate culture, and is not fully applicable to the rest of the soilless cultures using various inorganic or organic substrates. In fact, watering the later, the frequency and duration of irrigation is much more critical for certain substrates with low water holding capacity, compared to soil.

With reference to water saving, certain soilless systems, for instance the close recirculated ones, undoubtedly economize water because drainage and evaporation from the surface is eliminated by the design and operational scheme of the systems (NFT, "closed" systems, sub-irrigated soilless culture). In addition, with soilless cultures more accurate control over the supply of water is practiced.

Furthermore, water culture and sub-irrigated substrate systems save much labor in the time-consuming task of checking and cleaning irrigation nozzles. On the contrary, crops grown on substrates and soil, require frequent examination of trippers as these can easily be blocked by calcium carbonate or other compounds especially with a "hard" water supply. The blockage problem can be eliminated either by acidification of nutrient solution or by pre-treatment of irrigation water.

4-Reduction of labor requirement

Out of soil production exclude all cultural practices associated with the cultivation of the soil, sterilization of soil, weed control, etc. Labor requirement for soilless culture is not similar to all soilless systems. Therefore, the system itself, the degree of automation, the type of substrate, the number of crops raised on each substrate, etc. but in any case, generally speaking, there is a saving in labor impute when soilless culture is employed.

5-Sterilization practices

The greenhouse soil must be free from any soil-born pathogens before the establishment of any new crop. Sterilization is a difficult and costly operation, but necessary and of great importance. It is justified because the greenhouse business require high investment in structures, facilities, plant materials, running costs, etc. and the need to obtain maximum yields and returns, is obvious to have an economically viable operation. The most effective method of soil sterilization is by steaming, but the method is expensive due to the high cost of energy and labour, therefore its application is eliminated. Chemical sterilization is less expensive but not without disadvantages, i.e. the use of formaldehyde had the problems of fumes which are highly phytotoxic and the most important chemical, methyl bromide, a very toxic material to handle, has the problem of chemical residues (bromide ions taken up by the crop) and environmental pollution.

It is therefore of great advantage the cultivation of crops outside of the soil as there is no need for sterilization when materials and substrates are used only for one time, because spreading of diseases is avoided. When "closed" soilless culture is used depending on the system, the need for sterilization varies, i.e. to clean "true hydroponic" culture structures, following the removal of all debris, etc., a dilute rate of formaldehyde is used, followed with clean water. In the NFT system the film that forms the gullies can be replaced. When solid substrates are used, steam or chemical sterilization should be applied if the material is to be used again. In this case the application of both is more easier and more economic but in any case sterilization of soilless culture systems is more easier than soil sterilization.

6-Control of root environment

Possibilities for more accurate control of root temperature, root oxygen supply are more easily to achieve in soilless cultures.

7-Multiple crops per year

Due to the absence of the cultivation techniques, operations like soil cultivation, soil sterilization etc., the number of crops per year is increased, in a given production area, because the time interval between crops is nearly zero.

8-Unsuitable soil

Soilless culture offers an ideal crop alternative to soil culture when there is no soil available at all, or there is no suitable soil for crop production, when soil salinity is high or there are toxic substances into the soil and finally there is an accumulation of soil pathogens into the soil.

Constraints of soilless cultures

1-High capital investment

Introduction of soilless systems involves an increase of inputs for the construction and maintenance, compared to the cultivation in soil. The degree of increase of inputs depends on the soilless system to be use and also the degree of perfection of control measures used by the particular system adopted, i.e. the initial cost for establishing an NFT system is higher compared to the rockwool system, but the annual running cost is lower with the NFT system. NFT system with metal trays and raised stands is more expensive than the corrugated asbestos sheets used for NFT lettuce production, etc. Sand culture is less expensive in certain countries. Perlite has lower cost in Greece, but is more expensive in U.K., etc. Economic data on the application of soilless culture varies from country to country as prices of materials and services are not the same.

Further to the above the cost of the greenhouse structure, the cost of the greenhouse environmental management devices and controls, which are of great importance for a successful soilless culture, should be taken into consideration. We assume that electricity and good quality water are available.

2-Increased technical demands on the management

To succeed with the soilless culture methods, one must have or to be able to learn and have some knowledge of how to grow the crop, plant physiology, elementary chemistry, familiarity with the control systems, etc. It is evident that soilless culture is not an easy operation. Furthermore, scientific and technical support from the research workers, extension services and private

enterprises dealing with all relevant materials and accessories for soilless culture, is of great importance.

Growing crops in restricted volume requires a higher standard of management. Successful commercial soilless cultures are demanding good management and skilled staff. Therefore, the person in charge must have a very wide range of skills, i.e. able to prepare and adjust the nutrient solutions, set and control electronic equipment, to have knowledge of plant physiology, to recognize and be able to control plant diseases. Risk of disease infections is much higher.

Reference also must be made to the simple forms of soilless systems. These are more easy to manage and are more suitable to be installed in areas where the knowledge and facilities are limited.

It is important to remember that soil with its buffering capacity “forgives” any mistake from the grower related to nutrient supply, but a small error in the composition of nutrient solution or the pH, the EC., will be harmful to plants in soilless culture. Failure to the power supply or water supply can mean total loss in a short period of time.

3-Risk of disease infections

In the “open soilless system” the risk of disease infections is lower, provided that drain solution flows away from the roots of the plants. In the “closed systems” or in systems when excess drain water flows along the roots of all plants, then if there is an infection with pathogens, all plants in the system become infected.

CHARACTERISTICS OF MATERIALS USED IN SOILLESS CULTURES

Technical specifications of structural materials used to built systems

A number of materials are used to construct the soilless growing systems, the most common are: polyethylene, polypropylene, PVC, polystyrene foam, aluminum, steels, asbestos corrugated sheets and concrete. The materials should be sustainable. Koning & van Weert (1992) (cited from Van Os, 1994) describe the specification these materials must have.

- no leakages during installation and use and possibility of measuring possible leakages.
- no damaging volatilization of damp or substances.
- resistance to steam sterilization, UV radiation and pesticides.
- taking back of materials after use and a guarantee of primary recycling by the suppliers.
- low costs

The above specifications refer to Holland but most of them could easily applied to other countries as well.

Technical specifications for substrates

According to Csaba, 1995 and Koning *et al.*, 1992, substrates must have the following properties:

- Inert (no reaction with the nutrients)
- pH neutral
- Porous
- Low density
- Hydrophilic

- Free from grit, heavy metals and radioactive pollutants
- Applicable in natural form without need for processing
- Can be mined or produced by the industry
- Has constant quality (no decrease of physical properties during use)
- Having a lifespan for at least three years
- Easy to use
- Low cost
- Recyclable or destroyed without hazard
- Resistant to sterilized several times without structural quality change.
- Pest free

Among the substrates that meet the above demands are rockwool, polyurethane foam, clay granulates, pumice stone, perlite, Irish peat, sand, etc.

The difficult problem of selection of the growing medium is overcome with the use of true hydroponic systems provided that the greenhouse structures are developed (construction, controls, etc.). The most well known methods are NFT, Plant Plain Hydroponic (roots develop between two plastic films) and Aeroponic. In these systems water can easily be sterilized, has a long life and does not create a waste flow. However, from the cultivation point of view, there are disadvantages like the great risks from mistakes and disturbances, power failure, the very low buffer capacity hence the danger of disease infection, etc.

SELECTION OF SUBSTRATE MATERIAL

A very important aspect of establishing soilless culture, is the selection of the proper growing media. The main criteria for selection of a particular substrate, should be based on:

- Agronomic characteristics of the substrates
- Technical level of cultivation
- Environmental conditions which can be provided (structure, controls and other facilities)
- Effect of substance on crop susceptibility to diseases
- Economic situation of the farm business
- Scientific support to the grower or level of education of the grower
- Availability of the substrate (local or imported)
- Cost of substrate
- Environmental effect of the substrate (pollution, etc.)
- Marketing prospects in remunerative prices of the produce

The available growing media and the desirable characteristics have already been presented. It remains to say few things about the established materials and the new ones which are under evaluation and look promising.

Rockwool

Good results have been obtained with rockwool in many countries and examples of using this material in commercial greenhouses are well known (Holland, France, U.K., Denmark, etc.), all having good control on the environmental growing factors and the application of nutrient solution. But there are still some disadvantages using rockwool, such as:

- The high cost, which in many countries remains a limiting factor.
- The recycling subject is still an unsolved problem in many countries.

- The rumour that rockwool produces carcinogenic and skin irritation effects which of course have not been proved scientifically (Csuba, 1995).

Polyurethane-ether foam (PUR)

Benoit and Ceustermans (1993a, 1993b, and 1994), introduced PUR (trade name "Aggrofoam"). It was used for 10 years and was steam treated for 8 years at 110°C. The authors expect is that this substrate can be used for cultivation for 15 years. PUR substrate gave satisfactory results and now is used in practice for growing vegetables in Belgium at 10% of the area (Benoit and Ceustermans, 1993). Also, the cost of this material is high and acts as limiting factor of its application in many countries.

In some countries other plastic substrates are available as growing media, i.e. "Oasis", "Styroplast", "Biolaston", etc. These are stable materials, they can be used for many years, they are relatively cheap, chemically inert and generally hydrophobic. Furthermore, they do have the problem of disposal.

Perlite

Perlite has very good physical characteristics, and high potential to be used as a closed water-efficient system in areas with good quality water or as an open system where poorer quality water dictates this. Several systems have been developed which use perlite as a substrate. These have been described by Wilson (1980), Adams (1989), Olympios (1992), Olympios *et al.* (1994) and Guler *et al.* (1995).

In the literature quite a big number of research papers have shown the superiority of perlite as a substrate for crop production. Reference will be made on the experience gained in Greece. Comparing perlite, rockwool and sand in open systems, yield and quality of sweet melon was evaluated. Results have shown that perlite gave similar results as rockwool and has the great advantage of the much lower cost (Guler *et al.*, 1995).

Similarly in another experiment natural pumiceous perlite, and row perlite gave similar results as horticultural perlite in both growth and production, when tomatoes were grown in open systems on these substrates (Olympios *et al.*, 1994).

Sand

In an experiment carried out in Egypt to compare the use of sand and rockwool for tomato production in recirculating systems under protected cultivation, it was found that sand was as productive as rockwool (Abou-Hadid *et al.*, 1987). Sand has the advantage of the low cost compared to rockwool whereas its high cost imposed an initial barrier for its use. They concluded that drip irrigation with sand, provided significant saving in water, power and could be managed more reliable in areas where skilled personnel is not readily available.

Muncini and Mugnozsa (1993), compared the production of Chinese cabbage in NFT and sand. The yield in NFT was higher (9,0 kgr/m²) compared to sand (6,3 kgr/m²), but the nitrate accumulation in leaf blades was higher in NFT (2900 mg/kg f w) compared to 1033 mg/kg f w in sand.

In Malaysia the utilization of sand as substrate was found suitable for the cultivation of tomatoes giving similar yield as that grown in the liquid hydroponic. Nutrient application and irrigation are important factors determining growth and yield in sand culture. Fertigation was reported the most efficient method of cultivation in sand culture (Fujiyama and Nagal, 1987).

In an experiment to investigate substrates \times volume \times irrigation frequencies, best results were given when 6 litres of sand were irrigated 4-5 times daily (Ismail *et al.*, 1993). The importance of proper irrigation management was evident when there was a 70% reduction in overall yield with one and two, compared to four or five irrigations daily.

In Eastern and South Spain sand is the most widespread growing media for soilless culture. The typical sand used in soilless systems in Spain is often excessively fine compared to the particle size suggested by Jensen and Collings (1985). It must be mentioned that sand availability in Spain is dramatically decreasing due to environmental protective regulations (Martinez and Abad, 1992).

The low air-filled porosity (AFP) found in sand is probably the reason for the lower yield in this substrate, in spite of the good levels for E.C. during the growing period and better availability of water compared to perlite and sepiolite (Martinez and Abad, 1992). This resulted a poor distribution of the root system within the substrate volume. Roots were developed only in the space between the bag cover and the sand, where more air exchange was possible as shown by Brian and Eliassal, (1980). The low AFP in sand makes even more important and accurate water management for this type of sand and it seems that is necessary to apply water less frequently. When comparing substrates in a common experiment, is a mistake to irrigate all substances the same way because due to different properties, moisture holding capacity and retention is different, therefore different substrates should be treated accordingly.

Nevertheless, in conclusion we can say that sand can be a good alternative media for soilless crop production, in countries where this material is in abundance and in low cost. The experience of Spain and Egypt in this respect can be a good base to use this substrate.

Sepiolite

In Spain, commercial-scale experiment was conducted in a polyethylene greenhouse to evaluate sand, perlite, rockwool slabs and sepiolite (a local fibrous structure, claystone material mainly based on hydrated magnesium silicate) alone or mixed with leonardite (3% by volume) and organic fertilizer with 60% content of humic substances.

Results shown that higher yields were obtained with perlite and sepiolite (4/20-mesh plus leonardite) and rockwool (Martinez and Abad, 1992). The authors suggest sepiolite as a new substrate for horticulture, because it has good performance under conditions of saline water, no pollutant effect and has a low cost. The total pore space of sepiolite is 78,13% the Air Filled Porosity 43,87% and the easily available water about 2%. Perlite and sand were the materials that kept the lowest E.C. until the end of the experiment.

NFT

Nutrient Film Technique (NFT), is one form of soilless production system, using only recirculating nutrient solution for the production of crops. The development of the NFT system removes the necessity for the determination of water requirements and provides the opportunity of more precise control over plant nutrition. The simplicity of the technique allowed the development of almost totally automated systems.

Also the flexibility of the NFT system has enabled it to be adapted to a wide range of crops (Burrage, 1992). The ability to control the root environment has led to practices of solution heating, variation in solution conductivity and intermittent flow, to control crop growth. The minimal use of water and nutrients has made it highly desirable in arid and semi-arid climates.

With the recent concern of pollution caused by and the cost involved in the open systems, (i.e. open rockwool production, open perlite, etc.) we may see in the future an expansion of NFT. It is a system that has considerable potential but requires a higher level of management than conventional production and in some areas this may be the main inhibitory factor for its expansion. NFT simplifies the work of the labour but places a greater responsibility on the management.

In Greece, a low cost NFT system for the production of lettuce has been developed and was accepted by the greenhouse growers. Plants are grown on suitably supported corrugated asbestos cement sheets, forming five to eight (5-8) parallel channels, 9 cm apart, 9 cm wide and 5 cm deep. These sheets are placed in position with a 1.5% slope. Polyethylene film is used to isolate the root system and nutrient solution from direct contact with the asbestos-cement sheet and expanded polystyrene sheets are used to cover the channels and support the plants. Several lettuce crops can be grown during the same season, assuring high income to the growers (Olympios, 1993).

In an experiment to study the difference between sweet pepper plant behaviour in NFT and rockwool, it was shown that the plants grown in NFT gave higher total yield than those grown in rockwool (Abou-Hadid and Burrage, 1994).

The NFT technique greatly simplifies watering, it eliminates soil cultivation and soil sterilization and ensures uniformity of nutrient supply, therefore it appears as an economically attractive cropping system. In this technique the use of water and nutrient is regulated to the minimum needed for plant growth and productivity. As the reaction of the various vegetable crops as well as the different cultivars of each vegetable crop react differently in the NFT, it is recommended to study the composition of the nutrient solution, the E.C., pH and root temperature to match the crop requirements under the Mediterranean environmental conditions.

Aeroponic culture

A soilless method which has been developed and evaluated in several countries but it is still at the experimental stage. As a soilless method it has an extra advantage, the increased plant density which can be used and the high water use efficiency (Abou-Hadid and Medany, 1994). Encouraging results were also reported by Leoni *et al.*, (1994) with tomatoes grown in High Density Aeroponic System (HDAS), 20-30 plants/m², where yields of 5.0 to 8.0 kg/ m² of good quality tomatoes were harvested from tomatoes pruned to single cluster, three months after transplanting. The system allows 4 cultivation cycles in one year (12 months).

ORGANIC SUBSTRATES

For more than 30 years organic substrates (peat moss, etc.), have been the dominating bulk material in substrates for growing plants. It is clear that organic substrate decay quickly due to microbiological actions and also they react chemically with the nutrient solution. This is a disadvantage of the organic materials as it is not easy to control these reactions, therefore it is necessary to interfere in the growing process, to adjust by the frequency of the nutrient application the changes in the E.C., pH and the levels of the trace elements. If the soilless system is closed, then more frequent chemical analysis of the solution is required (Benoit and Ceustermans, 1994).

Peat and other organic substrates

Peat is a very good substrate, used successfully for many years, but now, due to environmental reasons other organic products are suggested for replacement, i.e. coconut coir, ricehusk, ruffia bark, straw from grass species. Moreover, there is a large number of composted organic products which have been studied for their use as horticultural substrates, such as sewage sludge, composted softwood and hardwood bark (Verdonck, 1983) or composted municipal yardwaste,

composted turkey broiler litter (Bilderback and Fonteno, 1994). The one-year compostable organic pine fibre "Hortifibre" was introduced by Benoit *et al.*, 1988, (cited from Benoit and Ceustermans, 1993). The material showed a number of microbiological and chemical reactions that were uncontrollable and therefore the growing technique requires modification, perhaps more frequent flows of nutrient solution with the first in the morning to last longer, so that to wash out the disproportionate nutrient ions.

It is interesting to mention the cork oak bark organic substrate which was used by Aguado *et al.*, 1993, and proved to be a suitable substrate for growing plants.

Organic substrates have a reasonable price, they can be disposed of without any detrimental effect on the environment or they can be recycled.

Marc

Pisanu *et al.* (1994) reported that the growth and production of gerbera on "marc" substrate was particularly interesting because of the low cost of the substrate and its great availability in Mediterranean Countries. Number of flowers produced on "mark" were similar to those produced in rockwool, although perlite gave significantly higher number of flowers per m², (195, 194 and 219 respectively).

WATER QUALITY

One of the most important factor for a successful production in soilless cultures (hydroponics or substrate cultures) is water quality and availability. Water can be available from rivers, lakes, rainwater, underground reservoirs, spring or mains water, from desalinization or from other treatments. The choice must be based mainly on quality, storage capacity and price (Van Assche and Vangheel, 1994).

PLANT DISEASES IN SOILLESS CULTURE

In the past, we thought that changing from soil culture to substrate or hydroponics culture it was possible to eliminate the dangerous soil born diseases and pathogens. Unfortunately, this is not the case. Transferring a plant from the soil with its natural buffering effect against physico-chemical and biological pathogenous influences to some "biological vacuum", has even increased the chance of epidemics (Van Assche and Vangheel, 1989). Most root - infecting pathogens also occur in these new cultivation systems.

Because of the absence of potential antagonists in substrate and hydroponic cultures, pathogens entering the systems will not meet any obstruction, therefore it will be multiplied and spread. The disease problems might not be the same or to the same extend in soilless culture as in soil culture, for example some minor pathogens in soil cultivations may in soilless develop into major pathogens, i.e. *Pythium*, *Phytophthora*, Cucumber Green Mottle Mosaic Virus and Tomato Mosaic Virus, etc. are easily transmitted in recirculating water.

The above problems, as suggested by Van Assche and Vangheed, (1994) can be faced by optimizing the plant's growing conditions (i.e. increasing the substrate's or the nutrient solution's buffering effect by adding humid acids or by introducing antagonistic bacteria into the substrate or hydroponic culture) or assisting plants to develop more "Cultivation Technical Resistance" (controlling the growth medium by balancing the nutrients or using the optimum temperature).

Phytiatry

Application of chemicals in soilless culture for the control of pathogens is an important aspect of production and must be carried out with increase care. In soil cultures possible dosage errors will not be punished due to the buffering effect of soil, but in soilless culture this is different and therefore the chemical's applicability in the nutrient solution should be examined very carefully (solubility, possible systemic activity and phytotoxicity). The residual level of the chemical in the plant and fruits also must be measured. Of course, application of chemical through the nutrient solution offers a number of important advantages as well, like: labour saving, homogenous spread and quick effect.

Treatment of nutrient solutions and substrates

Soilless culture requires high technological knowledge, advanced technological equipment and skill from the side of the producer in order to apply preventing and control phytiatric treatments.

In the case of recirculating nutrient solutions (close systems) disinfestation is of importance and various physical principles can be applied such as heating, ultra - sonication, ozone treatment, UV - radiation and filtration.

Ultra - violet radiation can be effective against plant pathogens providing the dose under controlled conditions is sufficient. The clarity of the solution must be high to avoid the blocking of the penetration of the UV rays. Removing suspended solids from the solution before the UV treatment by filtering is necessary to improve the clarity. Using sand filter is a satisfactory filtering device. Ultra - violet is electromagnetic radiation with a wavelength between 100 - 400 nm. In this area, UV rays with a wavelength of 200 - 280 nm (short wave) have a strong germicidal effect with an optimum at 253,7 nm (Gelzhäuser *et al.*, 1985 cited from Rania, 1994). These UV rays destruct microorganisms by a photochemical reaction.

Reuse substrates (rockwool, polyurethane) can be disinfested by steam at a temperature of 100-110°C for 10 minutes to prevent infestation of the culture on these materials (Benoit and Ceustermans, 1994).

IMPORTANCE OF GROWING ENVIRONMENTAL CONDITIONS

There is no doubt that for a successful crop production under protected cultivation it is important to control the climatic and growth factors such as temperature, ventilation, radiation, CO₂ concentration and plant nutrition. However, one of the most important factor in soilless culture is the fertirrigation.

Most of the greenhouses in the Mediterranean Countries are simple structures, covered with plastic films, with simple equipment and technologies for both irrigation and climate control. The choice of such a production system is mainly due to the low level of investment the growers of these Countries could support. Because the climatic conditions in these Countries vary considerable during the year and also there are variations between Countries and within the Country at different locations, there are serious production problems which affect the quantity and the quality of the products. So, it is important to find out and recommend how to produce better (quantity and quality) with the existing structures, which in many times production factors like temperature, water quality etc., are at sub-optimum levels.

To have good results with soilless cultures, it is necessary to have some control of the environmental factors, temperature, humidity, ventilation, etc. This means improvement of

greenhouse structures and greenhouse equipment. Also, growing conditions must be applied to near optimum levels as possible, for root growth and activity, top growth, for production, etc. Furthermore, good control of nutrient supply, optimum temperature of the solution and solution free from pathogens must be our efforts.

There is increasing awareness among scientists and protected crops growers, of the potential pollution problems associated with conventional hydroponic growing systems (open systems). In open systems it is standard practice to feed approximately 30% above the plant's theoretical requirements, in order to allow for inaccuracies in irrigation systems. The excess containing high levels of nutrients run to waste together with any fungicides which may have been applied to the crop. This run-off liquid goes into the greenhouse soil and may then reach underground water (Hardgrave, 1993).

However the surplus of the nutrient solution must be as small as possible. There has been experimental evidence that high crop yields can be reached even with minimal nutrient solution excess (2 to 6%), if the supply of water and plant nutrients are adequately controlled.

It is of great importance to reduce nutrient leaching from soilless production systems to ground and surface waters, therefore "closed systems" should be employed. Recirculating solutions can be used successfully provided that good quality water is available, and nutrient additions match uptake by the plants. These systems of course require high technological equipment and can imply risks of a rapid spread of root diseases (Rania *et al.*, 1988).

The definition "closed systems" means that emission routes are closed in such way, that soil, water and air will not be polluted and wastes are removed only in a controlled way. The "closed systems" referred to cultures in which plants are grown out of the soil on artificial substrates. By growing in artificial substrates, chemical sterilization can be avoided and there is no leaching of chemicals to the soil and ground or surface water. However, leaching of chemicals by evaporation through the glasshouse windows might be very difficult to prevent in this way (Ammerlaan, 1994).

Open and closed growing methods were compared by Bartosik *et al.*, 1993 with tomatoes grown in peat and rockwool. The advised fertigation levels in tomatoes growing in the open method was up to 40% more than the plant requires. The comparison between open and closed growing systems indicated that it is possible to prevent leaching by using closed growing system, but not without disadvantages (less yield).

PERSPECTIVES

To change from soil cultivation to soilless culture is not a simple operation for most of the Mediterranean Countries and this is a result of:

- lack of technical background of the new technique among growers and horticulturists in many countries.
- adaptation of soilless technology to the very simple greenhouse installations, those extensively used in Mediterranean Countries is not easy.
- the substrates in the international markets, i.e. rockwool, perlite, peat, etc., are expensive.

In the different Mediterranean Countries the interest should be concentrated to develop and evaluate the local substrates to be used for soilless culture. Some times there is a need to transfer waste materials into useful products.

So, local-low cost and well known to growers materials can be used, with the necessary alteration as required by the soilless culture methods, for example, local sand (is the most abundant material

in many Mediterranean Countries), gravel, perlite, pumice, sepiolite, etc. It is important to find a substrate with a good performance under local conditions of water quality, of low cost and with no pollution effect.

Due to the problems in productivity in Mediterranean Countries in soil cultivation (reported earlier), we must emphasize the importance of the soilless culture and the need to develop and adapt a suitable, technically simple, reliable, safe to use and of low cost hydroponic system for the Mediterranean Countries so as to be able to produce in simple structures of low investments and low management technology.

The suggestions proposed by Baille (1994), show the necessary steps to follow, if soilless culture is to be promoted successfully in the Mediterranean Countries with less technological development at present.

- Control of climatic factors. This means improvement in both structures (design, etc.) and equipment efficiency (control of air temperature, RH, air movement and ventilation, CO₂ enrichment, etc.).
- Improve root environment that means good control of water and nutrient supply (i.e. nutrient composition, pH, E.C., etc.), optimum temperature and control of pathogens (sterilization of growing media and nutrient solution when recirculating).
- Growers must be trained to use equipments and controls for climate and irrigation control.

In principle, most substrates are suitable for successful soilless culture if adequately supplied with water and nutrients. The optimization of factors such as the temperature and humidity of the aerial environment and aeration, nutrition and temperature in the root zone is essential if the full potential of hydroponic culture for plant growth, fruit yield and quality is to be achieved.

Ecological aspects are becoming more and more important when choosing substrates for soilless culture and economic efficiency is taken into account as well. The two main environmental problems of substrate culture are the cumulating waste substrate material and the effluent of the overdosed nutrient solution from the substrate into the soil, resulting in pollution of the soil and the ground water. The solution to the problem is to use substrates which can be recycled and to adopt the “closed soilless systems”.

It must be stressed that “closed systems” have a limited expansion in Mediterranean Countries so far because they have high initial costs, management problems and there is lack of experience in this sector not only among producers, but to some extent among researchers and extension specialists.

In conclusion, it can be said that considerable progress has been made recently in the development of economically viable soilless systems and there is a relatively broad commercial application now-a-days in Countries with advanced agricultural technology, i.e. Holland, other Northern European Countries, Japan, USA, etc. In many other countries, including the Mediterranean Countries with less agricultural technological development, there are still in their initial phase of development in spite of promising research findings.

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