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DIFFERENT SOILLESS CULTURE SYSTEMS AND THEIR MANAGEMENT

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ABSTRACT
Soilless culture is growing plants without use of soil as a rooting medium, and divided into water culture and substrate culture. Among the water culture techniques, float hydroponics is adopted for the cultivation of fresh-cut leafy vegetables and aromatic plants. Substrate culture by using plastic bags has been applied successfully at commercial level for fruiting vegetables. Production scale, crops, growing cycles and length of each cycle, cost and management skills should be considered as well as environmental concerns in the decision of soilless culture system. Therefore, closed loop systems have gained importance for increasing sustainability in soilless cultivation. This presentation aims to summarize different soilless culture systems and the potential of their use in vegetable production.

Keywords: Hydroponics, substrates, open system, closed system.

INTRODUCTION
The growing of plants without soil has developed from the findings of experiments carried out to determine what substances make plants grow and the composition of plants. These plant nutrition experiments date back as early as the 1600s. However, plants were being grown without soil for earlier than this. The hanging gardens of Babylon, the floating gardens of the Aztecs of Mexico and those of the Chinese are examples of hydroponic culture. Egyptian hieroglyphic records dating back to several hundred years B.C. describe the growing of plants in water (Resh, 1991).
Interest in practical application of this technique did not develop until about 1925 when the greenhouse industry expressed interest in its use in USA. Greenhouse soils had to be replaced frequently to overcome problems of soil structure, fertility and pests. As a result, research workers became aware of the potential use of soilless culture to replace conventional soil culture methods. Between 1925 and 1935, extensive development took place in modifying the laboratory techniques of nutriculture to large-scale crop production. The first study outside the laboratory was realised in USA by Gericke in 1929 by growing plants in nutrient solution. During the World War II, US Army used this technique to produce vegetables in some non-arable islands in Pacific Ocean and regions contaminated due to the war operations. Besides pure nutrient solution (water culture), an aggregate medium was introduced to provide support and aeration to the root system. Sand and gravel were the most popular aggregate materials at that time. The interest in applying soilless cultivation at commercial level gradually increased by the end of 1960's in that time Nutrient Film Technique (NFT) was introduced in the UK and rockwool was introduced as growing medium in Denmark. In the following years, there was a great expansion of rockwool to grow cops in many countries especially as an alternative to steam sterilisation of which cost increased due to energy crisis during 1970's. Soilless cultivation has gained importance as an alternative to methyl bromide (MeBr) in 2000's (Resh, 1991; Savvas, 2002; Raviv and Lieth, 2008).
Soilless cultivation offers numerous advantages (Savvas, 2002; Pardossi et al., 2004; Savvas et al., 2013; Gül, 2017) such as absence of soil-borne pathogens, safe alternative to soil disinfection, possibility to cultivate greenhouse crops with high yield and quality in non-arable soils, precise control of nutrition, avoidance of soil tillage and preparation, thereby increasing crop length and total yield in greenhouses, enhancement of early yield in crops, possibility to protect environment by closed systems that increase water and fertilizer saving and enable a drastic reduction of nutrient leaching from greenhouses to the environment. However, soilless cultivation needs higher initial investment costs and technical knowledge. Therefore, there are differences between countries in respect to expansion of soilless cultivation that is higher in the countries; the average greenhouse size per enterprise is high. On the other hand, soilless cultivation is progressing slowly in low technology greenhouses based on favourable natural conditions in most of the Mediterranean countries (Savvas, 2002; Gül, 2017).

SOILLESS CULTURE SYSTEMS

In the first study at a big scale by Gericke, water culture was used and his system was later termed hydroponics derived from two Greek words hydro "water" and ponos "labour" literally "water working" (Resh, 1991). Later on, the use of the term "soilless culture" is accepted rather than "hydroponics" to describe all soilless cultivation techniques since the use of the term "hydroponics" is not appropriate especially for organic substrates. On the other hand, many authors still use the term "hydroponics" as a synonym to "soilless culture" (Savvas, 2002). Soilless culture can be classified as (1) Water culture and (2) Substrate culture:

WATER CULTURE

The basic requirements of water culture are root aeration, darkness at the root zone and plant support (Resh, 1991). There are different water culture systems (Savvas et al., 2013) namely Deep Water Culture (DWC), Float Hydroponics, Nutrient Film Technique (NFT), Deep Flow Technique (DFT) and Aeroponics.

DEEP WATER CULTURE (DWC)

It was the first hydroponic system for commercial crop production created by Gericke in 1929. The roots of the plants are wholly or partially immersed in the nutrient solution with a depth of 15 cm. Although the system was tested in several countries, it was not commercially become wider due to the limited air-water exchange area, compared to the volume of the solution, and the low diffusion coefficient of oxygen in the water resulting in hypoxia occurred at rhizosphere. In Japan, Gericke's system is improved by recirculating the solution and the by forced aeration (Savvas et al., 2013).

FLOAT HYDROPONICS

Floating system was designed and developed at the University of Arizona in 1980; mainly designed for seedling growing; however, it is used for plant growing from sowing until harvest of leafy vegetables (Morgan, 1999). In this system the sowing is performed directly in polystyrene/styrofoam panels or trays/viols containing substrates such as perlite, pumice, peat etc. After germination, panels are placed to float in tanks containing the nutrient solution (Pardossi et al., 2005). The depth of the tanks is 0.20-0.30 m and they are made of low cost material (concrete, bricks, wooden planks) or directly dug into the greenhouse. Tanks are sealed (e.g. waterproofing with PE film) and filled with nutrient solution (150-250 litre.m^{-2}) (Savvas et al., 2013).

During the last decade, floating systems has become popular since the nutrient and water management is extremely simple especially for baby leafy vegetables (lettuce, rocket, spinach, lamb's lettuce, watercress etc.) and herbs (parsley, basil, oregano, thyme, dill etc.) (Alberici et al., 2008). This kind of water culture systems allow more plants in the unit area, and clean crops, reducing sanitary risk and nitrate accumulation improve uniformity of growth and automation of cultural techniques. It is more the most suitable hydroponic system for short-cycle cultivation such as baby leaf vegetables that are harvested within 3-6 weeks from sowing (Gonella et al., 2003; Cocetta et al., 2007). Attention should be paid to the aeration and management of the nutrient solution and the depth of the pool in the floating systems.

NUTRIENT FILM TECHNIQUE (NFT)

NFT is a water culture technique in which plants are grown with their root systems contained in a trough or channel or gully which nutrient solution is circulated. The main features of an NFT system are a catchment tank containing the nutrient solution, a pump to circulate the solution and a series of pipes distributing the solution to the heads of the growing troughs, through which the solution falls by gravity down the catchment tank (Savvas et al., 2013).

The nutrient film technique (NFT) has been reported to have many advantages as follows: Watering is greatly simplified, since it is no longer necessary to make day-to-day assessments of water requirements and the tedious task of cleaning blocked irrigation nozzles is eliminated. Uniformity of nutrient supply is ensured. Root temperature may be raised whenever required. The rapid turn-round of crops is readily achieved. Pollution of environment is minimised by reducing water and nutrient loss and using minimal substrate. However, it generally requires a higher grade of management; decisions have to be taken at relatively short notice since there is no buffer capacity (Burrage, 1999).

In NFT, nutrient solution is circulated continuously or intermittently. Intermittent flow is practised mainly to control the growth of tomatoes and at the same time to save electricity and to reduce wear of the pumps. Intermittent circulation is based on time clock or solar integration. The time-clock offers a cheap but

relatively inflexible system, whilst the solar integrator is a more expensive approach, which can compensate for changes in the light conditions (Graves and Hurd, 1983).
Comparison of NFT with the conventional soil system in different crops and the increase in yield, composition of nutrient solution, etc. under Mediterranean conditions have been well documented: In the comparison of NFT with closed substrate culture, NFT increased the yield changing between 8-22 %, however, it was concluded that by the increase of solution temperature, some pathogens (*Pythium* spp.) could limit the production (Gül et al., 2001). Also in some researches conducted in Mediterranean Region, it was determined that intermittent flow increased early yield but had no effect on final yield (El-Behairy et al. 1991; El-Asdoudi et al., 1993; Economakis, 1993). Recently, also our results showed that effect of the regime of nutrient solution circulation on tomato yield changed according to production season. The intermittent flow resulted in a marked increase compared to continuous flow in terms of early yield in autumn. However, there was no significant difference between continuous and intermittent circulation regimes in respect to both early and total yields in spring (Gül et al., 2000). Similar results were obtained in lettuce crop (Tüzel et al., 2003).

DEEP FLOW TECHNIQUE (DFT)

In this technique, the nutrient solution is pumped around the troughs, mainly for aeration. The troughs are always full of nutrient solution in which roots are suspended. The depth of the nutrient solution is 5-15 cm which differs the system from NFT in which water stream is 1-2 mm depth (Savvas et al., 2013).

AEROPONICS

Aeroponics is the growing of plants in an opaque trough or supporting container in which their roots are suspended and bathed in a nutrient mist. The critical aspects of the technique are the character of the aeroponic, frequency of root exposure and composition of the nutrient solution. Spraying usually lasts 30-60 seconds, and their frequency varies according to species, plant growth stage, growing season and time of the day. At each nebulization, the drainage is collected at the bottom of the modules and recirculated (Savvas et al., 2013).

SUBSTRATE CULTURE

In such systems, a solid substrate provides support to the plants. As in liquid systems, the nutrient solution is delivered directly to the plant roots. Growing media or substrates are classified according to their origins as follows (Gruda et al., 2013):

1. Organic substrates
   - 1.1. Natural (Peat, coir, plant wastes – sawdust, bark, rice hulls etc.)
   - 1.2. Synthetic (Polyurethane)
2. Inorganic
   - 2.1. Natural (Sand, gravel, tuff, pumice)
   - 2.2. Processed (Expanded clay, perlite, rockwool, vermiculite)

The ideal soilless growing medium should have some physical and chemical properties such as a uniform texture that drains well but retains nutrients and water for the root system; low bulk density to facilitate installation and transportation (between 190 and 700 kg/m^3); high porosity (between 50% and 85%); particle-size distribution to maintain good balance between air and water retention (between 0.25-0.5 mm); a pH between 5.0 and 6.5, which can also be adjusted easily; low content of soluble salts; chemical inertia which means that the substrate does not affect the nutrient solution by releasing inorganic ions or immobilising nutrients, ability to maintain original characteristics so that it can be used for many successive cultivation cycles; absence of pathogens and pests (but not necessarily sterile), and free of any compounds toxic to plants and ability to be produced in uniform batches (to allow the use of consistent fertilisation programmes) (Pardossi et al., 2011).
Substrate use changes according to country. For example, the main substrate used for soilless cultivation is rockwool in the Netherlands, whereas sawdust culture is especially popular in areas having a large forest industry such as the West coast of Canada and the Pacific North West of the United States. The use of gravel or sand beds in a closed recirculating nutrient solution system is probably the oldest commercial substrate culture system. It was widely used from the 1930s to the 1950s and remains in use on a limited basis today. Peat was the most popular growing medium in 1970s, but it is not used anymore due to the increasing environmental concern. Nowadays, the most common substrates are rockwool, cocopeat (coir) and perlite.

All forms of substrate culture involves growing plants in some kind of a container-a trough, pot, etc. or pre-packed bags or encased slabs.

BAG CULTURE

Plastic bags filled with porous slabs or loose granules are used. These bags may be either manufactured and purchased as ready-to use bags or filled by the grower. The most common slab-type growing media are rockwool and coir. The slabs are usually 100 cm in length, 15-20 cm in width and 6-12 cm in height. The most common granulated material used in Mediterranean countries is perlite.

Bags are placed into channels or panels to collect the drainage solution. On the top of them, planting holes are cut. The amount of planting holes varies depending on the crop but as a guide, 3-5 tomato can be planted into a slab/bag 90-100 cm long. As soon as planting holes are ready, a dripper per hole is placed, and the substrate is saturated with nutrient solution. Saturation is maintained for 24-48 hours to allow the substrate to absorb the solution. Then, small holes or cuts are made along the base of the plastic envelope to allow excess nutrient solution to drain. Plants are transplanted and one dripper is fixed next to each plant.

Less commonly, the bags are placed vertically with open tops for single-plant growing. These have the disadvantages of being less convenient to transport, requiring more water, and maintaining less even levels of moisture (Savvas et al., 2013).

CONTAINER CULTURE

Container culture includes different containers such as PE, PVC or polystyrene buckets or pots. Container volumes vary from 12 to 18 L and the number of plants per container is 1-2 for high cash crops such as tomato. The depth of container is important for adequate root development and plant growth, and the deeper the container the higher the ratio of air to water in the substrate. The choice of the container depth depends on crop, length of growing cycle and substrate. Generally a depth of more than 20 cm is required. Drip irrigation system is used to provide nutrient solution for each plant individually and drainage is usually assured by overflow opening in the base of the container. The growing media mainly used in container culture are coir and perlite (Savvas et al., 2013).

TROUGH CULTURE

In trough culture, the plants grow on plastic or plastic lined troughs built above ground. The depth of troughs changes between 10 and 35 cm depending on the substrate and particle size (for instance 0.3-0.5 mm particles require a depth of at least 35 cm). The troughs should have a uniform slope of 0.5%. A drain pipe is placed on the bottom of the trough from one end to the other. Plants are placed at normal spacing and drip irrigation is used to feed each plant individually. The growing media used commonly in trough culture are coir, perlite, sawdust, sand and gravel (Savvas et al., 2013).

NUTRITION IN SOILLESS CULTURE

In soilless culture, all essential plant nutrients are supplied via the nutrient solution excluding carbon, which is taken up from the air as CO_2. Inorganic fertilizers are used as nutrient sources in order to prepare nutrient solutions containing all essential nutrients, with the exception of iron, which is added in chelated form, to improve its availability for the plants. Most fertilizers used to prepare nutrient solutions in soilless culture are highly soluble inorganic salts but some inorganic acids are also used (Savvas et al., 2013).

There are limited researches on the use of organic fertilizers in greenhouse soilless vegetable production (Jiang et al., 2004). The main difference between the organic and inorganic fertilizers is the release timing of nutrients which is related to the nutrient solution characteristics and also to the substrate itself (Kaya et al., 2008). More research is needed to develop to optimize plant nutrition using organically-certified fertilizers to satisfy plant need (Raviv, 2017). However in most countries soilless culture is not an acceptable method in organic agriculture yet.

OPEN AND CLOSED SYSTEMS

The nutrient solution with complete nutrients necessary for crops is applied to plants in two ways: In open systems the water and nutrients are supplied and collected drained nutrient solution is thrown out of the system. In closed systems the drained nutrient solution is recovered, replenished and recycled. Closed system is most obvious way to save water and fertilizer and to reduce environmental impact due to the discharge of excess nutrients from greenhouses. However there are the risks in terms of spreading of soil-born pathogens, the increase of EC due to the accumulation of unused ions and imbalance of the nutrients. Thus, this system required more technical knowledge, sterilization of the solution and control of the nutrient solution (Raviv and Lieth, 2007). In practice recirculating nutrient solution is disinfected by UV radiation (Wohanka, 2002) and replaced time to time in order to eliminate or reduce those risks within the system.

Among the soilless culture techniques, open substrate culture seems to be more promising due to its high adaptability to the farmers' conditions. However, the substrate as a method itself proved to create environmental problems such as the disposal of the substrate and drained nutrient solution which may result in soil eutrophication and ground water pollution (Benoit and Ceustermans, 1995; Lopez et al., 1998).

In countries where soilless culture is applied commercially, open soilless cultivation systems have created pollution problems resulting in a consequent transition to closed systems. The main advantages of the closed systems over the open ones are the reduction in water and nutrient loss to the environment resulting in better water-use efficiency. Also, closed systems use minimal substrate, so the problem of pollution of the environment from its disposal is also reduced (Putra and Yuliando, 2015). Closed systems increase water, nutrient and pesticide use efficiency and decrease their impact on the environment but a specific system needs to be developed for each crop (Böhme, 1996; Van Os et al., 1998).

Results obtained from the research related to cucumber growing indicated that there was no significant difference in plant growth, yield and quality of fruits in open and closed systems, whereas, closed system decreased water and nutrient consumption by about 22 and 35 %, respectively (Gül et al., 1999; Tüzel et al., 1999). Some other findings reveal an average nutrient saving of 32-34 % in tomato (Tüzel et al., 2000), 48 % in rose and 15 % in chrysanthemum production (Van Os, 1999). Also, closed systems reduced the amount of wasted water by up to 3.4 times compared to the open system (Tüzel et al., 2002).

CONCLUSIONS

Among the water culture techniques, float hydroponics is adopted for the cultivation of fresh-cut leafy vegetables and aromatic plants. Substrate culture by using plastic bags is applied successfully at commercial level for high cash crops. There are also simplified systems for small scale production.

Standards developed to ensure consumer confidence in terms of traceability, health and environment; the necessity of agriculture in places where water is becoming a limited resource and in non-arable soils where traditional techniques do not allow plant production are signs that the area of soilless cultivation will continue to increase in the future. However, it is important to select the appropriate system for a successful commercial production.

Production scale, crops, growing cycles and length of each cycle, cost and management skills should be considered as well as environmental concerns in the decision of soilless culture system. The future lies in systems that minimise their impact on the environment; closed systems where the nutrient solution is retained within the system and ground water pollution is reduced to a minimum.

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