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Soilless Culture System to Support Water Use Efficiency and Product Quality: a Review

Agung Putra P.*, Henry Yuliando

Department of Agro-industrial Technology, Universitas Gadjah Mada, Jl. Flora 1 Bulaksumur, Yogyakarta 55281, Indonesia

Abstract

The driving force of future agricultural industry is to provide sufficient yield that satisfy the needs of consumers and meet their interests in terms of quality. Soilless cultivation is intensively used in protected agriculture to improve control over the growing environment and to avoid uncertainties in the water and nutrient status of the soil. Recently the type of soilless culture transformed from open to close-loop system. This system is known for better result in water use efficiency, while maintaining the quality of the yield. This study aims to describe the specific purpose of soilless culture specifically in close-loop system and how substrate nutrition produces the better quality of the yields.

Keywords: close-loop system; nutrition; quality; soilless culture; water use efficiency

1. Introduction

Drought occurs in many parts of the world. Extreme temperatures, chemical toxicity, and oxidative stress also made the biosphere facing a huge problems and it affecting agricultural system. In the other hand, population rose every year and became more aware to the quality, quantity, and healthiness of what they have consumed. Those facts created the challenges in agriculture cultivation system to provide the system that increase the productivity, improve the product quality, and more-effective management system of resources. Greenhouse and hydroponic cultivation being developed rapidly to solve quality issues of agricultural product and out-of-season production. The processes of greenhouse production have greatly advanced in the last several decades. This development has usually

* Corresponding author. Tel.: +62-274-551219; fax: +62-274-551219
E-mail address: agungputra.pamungkas@yahoo.com

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been accompanied with the development of Soilless Culture Systems (SCSs), which is the most intensive and effective production method in today's agriculture industry (Dorais, et al., 2001; Grillas, et al., 2001). The SCSs guarantee flexibility and intensification and provide high crop yield and high-quality products, even in areas with adverse growing conditions (Grillas et al., 2001). This study aims to review and summarize the soilless culture systems to support the quality of agriculture products and to analyze the effectivity of the system in maintaining the water use during cultivation.

2. Terminology, Advantages, Disadvantages, and Classification of SCSs

Soilless culture can be defined as "any method of growing plants without the use of soil as a rooting medium, in which the inorganic nutrients absorbed by the roots are supplied via the irrigation water". The fertilizers containing the nutrients to be supplied to the crop are dissolved in the appropriate concentration in the irrigation water and the resultant solution is referred to as "nutrient solution" (Savvas, D. et al., 2013).

In soilless crops, the plant roots may grow either in porous media (substrates), which are frequently irrigated with nutrient solution, or directly in nutrient solution without any solid phase. In recent decades, supplying nutrient solution to plants to optimize crop nutrition (fertigation or liquid fertilization) has become routine cultural practice, not only in soilless culture but also in soil-grown greenhouse crops. Hence, the drastically restricted volume of the rooting medium and its uniformity are the only characteristics of soilless cultivated crops differentiating them from crops grown in the soil (Savvas, D. et al., 2013).

The advantages of this system are: absence of soil-borne pathogens; safe alternative to soil disinfection; nutrients and water are applied more evenly to the plants, therefore reducing wastage and providing a situation closer to the ideal growing conditions; soilless cultivation has the capacity for increased yield. Improvement in crop production could be more than 10-fold; possibility to cultivate greenhouse crops and achieve high yields and good quality, even in saline or sodic soils, or in non-arable soils with poor structure (accounting for much of the world's cultivable land); enhancement of early yield in crops planted during the cold season, because of higher temperatures in the root zone during the day; respect for environmental policies (e.g. reduction of fertilizer application and restriction or elimination of nutrient leaching from greenhouses to the environment) – therefore, in many countries, the application of closed hydroponic systems in greenhouses is compulsory by legislation, particularly in environmentally protected areas, or those with limited water resources (Burrage, S.W., 2014; Savvas, D. et al, 2013).

Despite the considerable advantages of commercial soilless culture, there are disadvantages limiting its expansion in some cases (Savvas, D. et al, 2013) such as high installation costs and technical skills requirements.

Soilless cultures are usually classified according to the type of plant support as substrate culture (artificial, mineral or organic growing media, or a mixture of these) and water culture or hydroponic, where roots are partially or completely dipped in the nutrient solution.

3. Transformation of open system soilless culture to close system for water efficiency

Traditional techniques in protected agriculture may be highly productive but their relative use of water may be high due to run off and infiltration; thus, the water-use efficiency may be relatively low. A good grower may achieve the same yield in soil as in soilless cultivation, but is likely to use 50–100% more water as a result of water losses from overwatering the soil and evaporation from the soil surface. If we consider yield per unit of water applied, soilless systems may increase yield substantially over soil-based systems. To reduce the water loss during cultivation, soilless system had developed from open to close system.

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.

Open systems, (see Fig. 1a.) where the water and nutrients are supplied as in conventional soil culture and the surplus (about 25%) nutrient and water is allowed to run to waste. The attraction of this technique is its similarity to soil as a growing medium and many similar techniques have been developed using a variety of inert media such as rockwool, sand, vermiculite, perlite and pumice. The two most important features relating to the substrate are that it is inert and that it has a great water-holding/release capacity. The maintenance of an appropriate water and nutrient level within the substrate is essential to prevent plant stress (Burrage, S.W., 2014).

Waste substrates can be used as a soil conditioner but its use is very limited. Rockwool can be recycled (re-used) for up to three years, after which it loses its water-holding capacity. A major disadvantage of open systems is that a proportion of the water and nutrients must be allowed to run to waste. This lowers water-use efficiency and contaminates groundwater supplies with salts. There is also a pollution problem arising from the need to dispose of the substrate on an annual or biannual basis (Burrage, S.W., 2014).

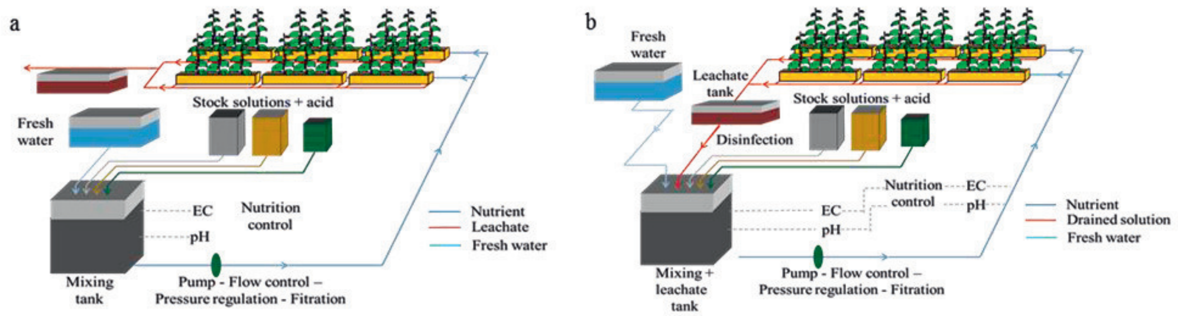

Fig. 1. (a) Open-loop; (b) Close-loop System of Soilless Culture.
(Source: Savvas et al., 2013)

Closed systems (see Fig. 1b.), such as nutrient film technique (NFT), where a film of solution is trapped between two sheets of polyethylene to form a growing channel. This provides a good contact between the recirculating solution and air, which is sufficient to maintain the oxygen level required by the roots without additional aeration of the solution. Because the solution is continually moving, there is very little short-term variation in salinity, unlike in the soil where salinity rises and falls with the water content. It is possible, therefore, to grow plants in much higher salinity in NFT solutions than would normally be used in soil-based production (Burrage, S.W., 2014).

Nutrient film technique (NFT) maximizes water-use efficiency by recycling all the water and nutrients not used by the plants. A thin film of nutrient solution maintained between two polyethylene sheets is provided to the plant roots, which grow into it. A pump delivers the solution to the higher end of the system, and the solution then flows under gravity back towards a storage trough (the system requires a minimum 1-in-100 gradient). Because of the risks of power and pump failure, most systems have both a back-up power supply and two pumps. Control of nutrient concentration is critical and tends to be automated via a conductivity meter; however, caution is required because of the risk of non-nutrient salt build-up giving false nutrition readings. The main requirement in changing from a soil-based system to NFT is the upgrade in management skills—the whole system reacts much faster than conventional (Burrage, S.W., 2014).

4. Impact of nutrition on yield

Proper nutrition factors such as EC, the types of nutrition, the composition of nutrient irrigated, and so on is the key factors to improve the quality of the yield. Savvas (2001) stated that EC is considered to be one of the most important properties of the nutrient solutions used in soilless culture. If the EC of a nutrient solution is too low, the supply of some nutrients to the crop may be inadequate. Similarly, when the EC is too high, the plants are exposed to salinity. However, the yield response of the plants to the EC of the nutrient solution may vary widely among different species. Therefore, for each cultivated plant species, the terms “too low” and “too high” need to be quantitatively defined based on experimental results.

5. Effect of EC and pH of nutrition to the yield

Savvas (2001) conducted the research about tomato cultivated in soilless culture and the results showed that the growth and yield responses of hydroponically grown plants to the total salt concentration in the nutrient solution may be described by the generalized model presented in Fig. 2. According to this model, if the EC is lower than a particular value (a), an increase in the EC to values not exceeding (a) enhances the yield of the crop. If the EC ranges between (a) and (t), where (t) is the upper critical EC level, known as salinity threshold value (STV), the yield of the crop remains constant. However, any further increase in the EC above (t) results in yield decrease. If all nutrients are included at sufficient levels in the nutrient solution, the decreases in growth and yield follow a linear pattern as the EC increases to higher levels than (t). The rate of yield decrease per unit increase of EC is termed salinity yield decrease (SYD). The impact of the increased EC on plant growth in hydroponics depends also on the prevailing climatic conditions. As a rule, the detrimental salinity effects are more pronounced under high light intensity and low air humidity.

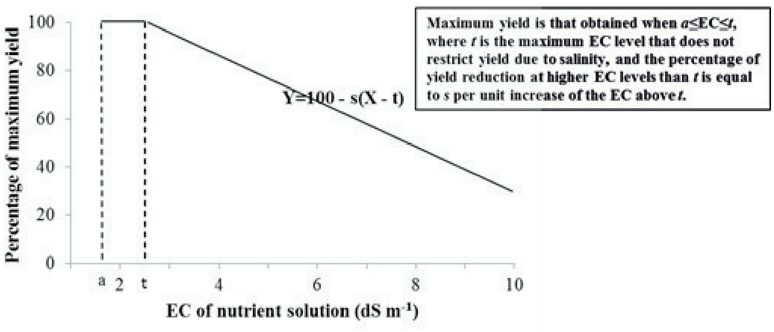

Fig. 2. Relationship between the relative yield (% of the maximum yield) in soilless-grown tomato crops and the electrical conductivity (*EC*) of the nutrient solution in the root zone.

The optimal pH in the root zone of most crop species grown hydroponically ranges from 5.5 to 6.5, although values between 5.0–5.5 and 6.5–7.0 may not cause problems in most crops (Adams, 2002). However, in soilless culture, when maintaining marginal values of the optimum pH range, the risk of exceeding or dropping below them for some time increases due to the limited volume of nutrient solution per plant that is available in the root zone. Most plants, when exposed to external pH levels > 7 or < 5, show growth restrictions (Sonneveld, 2002).

Different plant species have different preferences with regard to nutrient ratios in the nutrient solution. Thus, the determination of the most favourable nutrient ratio for each species is of major importance. Most experiments concerned with effects of nutrient ratios in nutrient solutions focused on the ratio between the metallic macronutrients (K:Ca:Mg or K:Ca), nutrient anion ratios, the N:K (or K:N) ratio and the ratio of $NH4^{+}$ to total nitrogen. The ratio between the metallic macronutrients is important for the maintenance of the EC in the root zone, since excessively high Ca:K or Mg:K may result in accumulation of these ions (Savvas, et. al., 2008).

5. Impact of growing media to the yield quality

Worldwide, a high percentage of the hydroponic industry uses inorganic growing media such as rockwool, sand, perlite, vermiculite, pumice, clays, expanded polystyrene, urea formaldehydes and others (Böhme et al., 2008), while only about 12% uses organic growing media (Donnan, 1998) such as peat, bark, wood residues (leaf mould, sawdust, barks), coir, bagasse, rice hulls and others. The most popular growing media for greenhouse production of vegetables is rockwool (Islam, 2008) (see Fig. 3). Rockwool is the preferred material because: 1) it is essentially almost chemically and biologically inert, making it free of any potential pests, diseases, and weed seeds; 2) rockwool slabs and blocks can be irrigated frequently as they drain freely and can thus be managed to provide an optimum ratio between air and water for crop production throughout the growing season (Bussell, Mckennie, 2004).

According to Gruda (2009), a number of authors have reported improved uniformity in weight, size and texture of tomatoes grown in soilless culture systems compared to those grown on soil. A few authors reported that soil culture could increase the size of tomatoes compared to soilless culture systems. Alan et al. (1994) grew tomato plants in soil, perlite, peat, sand, pumice and different combinations of them. Their results showed that the highest total as well as marketable yield was produced with a mixture of 80% pumice + 10% perlite + 10% peat medium, providing about 30% more product in comparison to the soil. A number of authors have reported that dry matter, sugar, soluble solids, vitamins and carotenoids content in tomatoes; acidity and taste have better marks when grown in soilless culture systems compared to soil (Gruda, 2009).

In addition to yield, the growing medium has shown effects on other plant parameters. Dry matter content was highest in lettuce grown in tea waste compost and lower in tree bark compost (Mastouri et al., 2005). Lettuce plants harvested from perlite or pumice culture had a lower dry matter, chlorophyll, Mg, Fe and Mn content and a higher titratable acidity as well as total N, P, and K content, in comparison with the plants harvested from the soil culture.

The effect of growing medium on the quality of tomatoes and cucumbers was investigated by determining texture, colour and taste by sensory evaluation and by chemical analysis (Luoto, 1984). Results indicated that the growing medium affected the dry matter content, pH and acidity as well as quality of tomato as judged. Tomatoes grown in peat were considered redder, softer and tastier and the taste differences were greatest at the beginning of the harvesting season. Rice hull alone resulted in increased sugar content of tomato fruit when compared with perlite (fine and coarse granule) (Lee et al., 1999).

Fruits from plants grown on Cocovita contained more dry matter than those grown on rockwool (Kobryń, 2002). The content of dry weight, ascorbic acid and sugars in fruit differed to a small extent between tomato plants grown on straw or rockwool (Nurzynski, 2006).

Chemical parameters of cucumber were also affected by the growing media, while medium had no effect on texture. The colour of cucumber at the end of the harvest season was affected by growing media (Luoto, 1984). Cucumber grown in mineral wool had the best taste (based on sensory evaluation, which was carried out immediately after harvesting) at the beginning of the harvesting season.

Different physiological disorders in broccoli include brown bud, bud deformation, bracting and hollow stem, which adversely affect the quality of the product. They are related to cultivar sensitiveness but also to nutritional disorders and/or to different stressing factors. Two growing media (perlite and coconut coir dust) were tested in plants grown in containers (San Bautista et al., 2005). The type of substrate did not affect yield, but when plants were grown in perlite, broccoli buds were more affected by the brown bud disorder (San Bautista et al., 2005).

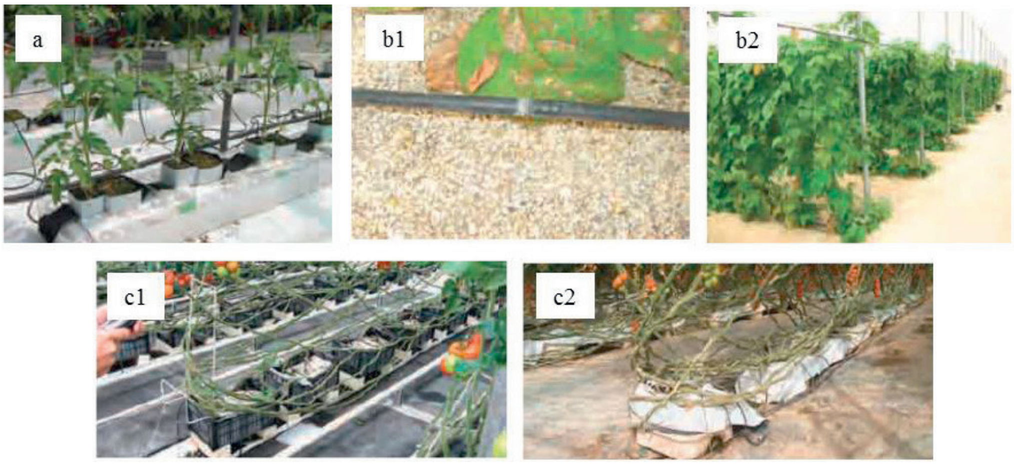

Fig. 3. Plants medium.

a) tomato grown on rockwool slabs
b) 1&2 beans soil cultivation
c) 1. Tomatoes grown on polystyrene buckets filled with coir
2. PE cases filled with perlite in Turkey (below)

6. Conclusion

Initially soilless production system was carried out by mimicking traditional methods based on production in soil or soil-based systems. Soilless culture can be the effective tool to increase the crop yield and, if closed irrigation systems are adopted could increase the water-use efficiency, also reduce the environmental impact of greenhouses and nurseries. By implementing the soilless cultivation system, some researchers yielded a better quality of agricultural products, which is expected to meet the consumer preferences. One of our concerns in determining the soilless cultivation system is an understanding of its benefits, which is a flexible growing method that lets the grower have full control over the growing environment, including the active root zone. These systems, which can increase the efficiency of water-usage while maintaining its quality, should be more intensively implemented in any scale to support eco-agriculture.

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