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Role of Soilless Culture Systems for Water Use Efficiency and Product Quality of Greenhouse Vegetables: Review

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Abstract

Open field/soil-based agriculture is facing some major challenges such as extreme temperatures, chemical toxicity, and oxidative stress 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. Under such circumstances, in near future it will become impossible to feed the entire population using open field system of agricultural production only. Naturally, soil-less culture is becoming more relevant in the present scenario, to cope-up with these challenges. In soil-less culture, plants are raised without soil, which is the most intensive, and effective production method in today's agriculture industry. Improved space and water conserving methods of food production under soil-less culture have shown some promising results all over the World. 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. By implementing the soilless cultivation system, some researchers yielded a better quality of agricultural products, which is expected to meet the consumer preferences.

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Greenhouse, Protected cultivation, Quality product, Soilless culture.

Introduction

Soilless culture is the modern cultivation system of plants that use either inert organic or inorganic substrate through nutrient solution nourishment. Possibly, it is the most intensive culture system utilizing all the resources efficiently for maximizing yield of crops and the most intense form of agricultural enterprises for commercial production of greenhouse vegetables (Dorais *et al.*, 2001). This protected cultivation system can control the growing environment through management of weather factors, amount and composition of nutrient solution and the growing medium. Therefore, quality of horticultural crops grown through soilless culture improves significantly compared to conventional soil culture (Xu *et al.*, 1995). This artificial growing system provides plants with mechanical support, water and mineral nutrient for higher growth and development. Over the years, hydroponics has been used sporadically throughout the world as a commercial means of growing both food and ornamental plants. Now a day, it has also been used as the standard methodology for plant biological researches in different disciplines (Asao, 2012). Afterward, several substrates have been evolved due to their unique properties for holding moisture, aeration, leaching or capillary action, and reuse potentiality. Soilless growing media are easier to handle and it may provide better growing environment (in terms

of one or more aspects of plant growth) compared to soil culture (Bilderback *et al.,* 2005; Mastouri *et al.,* 2005).

The problems in agricultural land use such as soil exhaustion, pest infestation or chemical interference are increasing greatly due to intensive cropping, injudicious application of pesticides or continuous monoculture (Sevgican, 1999). In this regard, soilless culture can avoid problems with monoculture of plants in the same land for years (Alan, 1990). It can provide several major advantages in the management of both plant nutrition and plant protection. The main reason of need for soil to soilless culture for horticultural crops is the problem related to proliferation of soil borne pathogen in the soil cultivation. Research studies reported that commercial production of greenhouse vegetables with soilless media adopted to reduce economic losses caused by soil-borne pathogens (Riviere and Caron, 2001). While other researchers reported that soilless culture can provide more efficient use of water and fertilizers, reduce root diseases, and facilitate cultivation of crops in areas where normal cultivation is not possible (Jensen, 1997). Thus, soil has been replacing by many organic and inorganic substrates, since they are disease and pest free inert material capable of holding required sufficient moisture and can be reused year after year.

The physical and hydraulic properties of soilless culture substrate are better than soil medium. In soil culture, plant root get higher water availability just after irrigation which cause lower oxygen content to be used by plant root and micro flora but in substrates optimum aeration is possible due to its leaching or pulling capacity by capillary action. Water application is several times higher in tomato (4 times) and lettuce (5 times) under conventional cultivation system compared to hydroponics. Root development and nutrient absorption is less in plants grown in soil but soilless substrates especially inorganic origin can hold adequate moisture, nutrient through their surface charge and also allow profuse root hair formation for efficient absorption. However, root volume is restricted in container based substrate culture. This limitation has several beneficial effects such as limited supply of nutrient is possible in soilless substrate culture (Dubik *et al.,* 1990) and also increases the root to root competition since there are more roots per unit volume of medium. Soilless culture is guarantee for enhancing quality production of horticultural crops, improving produce quality beneficial to human health, economics of reutilization of once used substrates (Asaduzzaman *et al.,* 2015). Therefore, the aim of this paper is to review and summarize the soilless culture systems effects on quality of greenhouse products and the effectivity of the system in maintaining the water use during cultivation.

Soilless culture Systems for Water use Efficiency and Quality Product

Soilless culture Systems for Water use Efficiency

Water is 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 substrates with low water holding capacity, compared to soil. With reference to water saving, certain soilless systems, for instance the closed or recirculated ones, undoubtedly economize water because drainage and evaporation from the surface eliminated by the design and operational scheme of the systems (Olympios, 1999).

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 because 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 (Burrage, 2014).

Soil-less systems use water in two different ways; they either recirculate the water continuously around the system or run the nutrient solution through the system

once and dispose of the water (run-to-waste). By circulating the nutrient solution within a closed system, hydroponics can use 4 times less water compared to the same yield from industrial field agriculture (Astee and Kishnani, 2010).

Soilless culture Systems for Quality Product

Horticultural produce from soilless culture have better qualities than those from conventional soil-based cultivation (Alan *et al.,* 1994; Xu *et al.,* 1995). Although the exact differences between qualities of vegetables grown in soil or hydroponics are difficult to determine (Schnitzler and Gruda, 2003) but soilless culture in greenhouse may be an alternative to soil culture for high-value vegetables crops including tomatoes, peppers, cucumbers, lettuce etc. In a study, Massantini *et al.*, (1988) found better taste, uniformity, color, texture and higher nutritional value in fruits grown in soilless culture than in soil cultivation methods. Similarly, it was also found that tomatoes produced in the nutrient film technique system were firmer and richer in vitamin C than those grown from soil-based plants. It also contained more sugar, acid and sodium, resulting in a distinct taste. Vegetables from organic substrate culture in greenhouse and poly tunnels are in high demand. Thus, in order to increase the qualities of horticultural produce appropriate fertilizer application, especially nitrogen and phosphorus along with growing substrate prepared from organic materials are suggested (Voogt *et al.,* 2011). Several studies showed that in general plants harvested from soilless culture had a lower dry weight and leaf area, however, significantly higher productivity were observed at the end of harvest (Frezza *et al.,* 2005). In this culture system, high concentration of nitrogenous fertilizer enhance the vigorous growth, which reduce the penetration of light intensity to the whole canopy due to huge foliage and thus reduce the accumulation of ascorbic acid in shaded parts. Enhanced growth of plants due to nitrogenous fertilizer may also have a relative dilution effect in plant tissue. Therefore, excess use of nitrogenous fertilizer increases the concentration of nitrate in plant tissue and simultaneously decreases that of ascorbic acid, it may have double negative effect on the quality of plant foods (Lee and Kader, 2000).

Soilless culture has been extensively used in tomato cultivation to increase the tomato fruits quality greatly around the world. It has been found that organic growing media produced higher yield and number of fruit than conventional growing system in greenhouse tomato production (Rippy *et al.,* 2004; Olle *et al.,* 2012). Many studies also suggested that tomato fruits grown in organic substrates had higher dry matter, vitamin C, and nitrogen compared to rockwool (Kowalczyk *et al.,* 2011a; Kowalczyk *et al.,* 2011b). The quality and quantity of tomato fruit in organic media found better than inorganic media (Permuzic *et al.,* 1998) and when it grown in different substrates the highest amount of total yield and number of fruits were harvested from perlite + rice hull while fruits with highest total soluble solids with sensorial qualities were from coco-peat substrate (Inden and Torres, 2004). And it was also reported that cucumber plants grown in nutrient film technique gave higher fruit quality than plants grown in perlite culture (Fernández-Trujillo *et al.,* 2004). Fruit qualities such as fruit firmness, total soluble solids, titratable acidity, ascorbic acid and carotenoids were found to be influenced by the soilless substrate used.

Research works have been conducted on soilless substrate for its influence on improvement of growth, yield and quality of pepper. Growing media composed of soil, peat, perlite, sand and pumice significantly affect the yield, fruit weight, ascorbic acid values and total soluble solids of pepper cultivars. Schnitzler *et al.*, (2004) observed better plant growth, fruit yield and quality in bell pepper (*Capsicum annuum* L.) grown in wood fiber substrate. Recent studies showed that plants grown on peat media had higher ascorbic acid content, total soluble solids, fruit number per plant and yield than its mixture with perlite or sand. Peat contains higher potassium than its mixture substrates (Gungor and Yildirim, 2013) and it has been reported that growing media with high potassium could increase the vitamin C content in plants.

In strawberry, Jafarnia *et al.,* (2010) reported total soluble solid were influenced by substrate and cultivars and fruit qualities such as vitamin C and titratable acidity were highest in rice husk substrate. From research results it is evident that soilless culture substrate affect the quality of strawberry and desirable fruit production is greatly depends on suitable choice of substrate and cultivars (Ameri *et al.,* 2012). Strawberries grown in greenhouses with different soilless growing media also showed their impact on phytochemical and nutritional composition (Tulipani *et al.,* 2008). Soilless growing system produced higher fruits with higher firmness in the green stage that is related to higher flesh thickness of fruits (Flores *et al.,* 2009).

Soilless culture has predominant influence on the floriculture industries and can provide means of best

quality flowers production throughout the year. For instance, in roses industry, higher yield and best quality of stems are entirely depends on physico-chemical properties of growing substrates. It was found that incorporation of rice hulls and press mud in traditional substrate found to be improved the growth and quality indices and increased flower yield of *Rosa hybrids* L. cvs. 'Kardinal', 'Anjlique' and 'Gold Medal' (Ahmad *et al.,* 2012). Fascella and Zizzo (2005) reported that soilless cultivation of roses in perlite or coconut coir dust increased yield and stem quality. This might due to the higher water holding capacity and cation exchange capacity of coconut coir, suggesting this organic substrate is one of the alternatives to peat for hydroponic culture. The highest quality of cut flowers of gypsophila in terms of stem length and number of branches per flower were obtained from plants grown in sawdust growing medium under soilless hydroponics with bag culture (Wahome *et al.,* 2011). High quality cut flowers of oriental hybrid lily were obtained in solid medium hydroponics when compared to mist culture system (Ryota *et al.,* 2002). The amount of nutrients in both organic and inorganic substrates changes during active vegetative growth of plants and its indication may be appeared in the leaves. Thus frequent analysis of substrate, at least once a moth is important for successful cultivation under soilless cultivation (Nurzynski *et al.,* 2001; Komosa *et al.,* 2010).

Soilless culture for Increased 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 inferior. Nevertheless, it is difficult to believe that the fast increase in area in soilless culture in the Netherlands and other European countries would have occurredunless commercial growers were confident of some yield increase to help offset the additional cost of soilless culture. It is of course understandable that if there are soil problems, (i.e. poor soil, saline soil, toxic soil, etc.), then soilless culture will produce much better crops. Most of them show advantages towards the soilless systems, but his was usually been due to a combination of factors such as reduction of labor, higher yields and the greater uniformity of quality due to them or uniform conditions of growth. However, it must be mentioned that in many experiments the management of crops in the soil is not controlled properly (Olympios, 1999).

Future Prospects of Soilless Culture for Greenhouse Crops

Soilless culture technique has been used successfully in the production of difficult to grown plants. It has great opportunities to explore the inabilities of production constraints involving environmental controls. Modification of culture methods and culture environment can lead to a sustainable crop production desirable for human beings. In this regards, hydroponic production of medicinal and aromatic herbs showed a new insight towards the mass production of these plants leading to high secondary metabolites yields and qualities (Hassanpouraghdam *et al.,* 2008). Soilless culture of medicinal herbs has many valuable advantages such as high yields, clean cultivation, year round production and production of drugs with minimum herbicide and pesticide residues (Dorais *et al.,* 2001; Manukyan *et al.,* 2004). Adequate supply of water and mineral nutrients increase the absorption and subsequently higher dry matter production both in aerial and underground parts of medicinal plants are the main advantages of substrate culture compared to field grown counterparts (Manukyan *et al.,* 2004; Hassanpouraghdam *et al.,* 2008). Therefore, successful soilless hydroponics of high value medicinal plant could be promising for pharmaceutical and food industries on meeting their high demands for *Chrysanthemum balsamita* (L.) Baill raw materials (Hassanpouraghdam *et al.,* 2010).

Transpiration influences transport and translocation of calcium in the plant body. It has been found that, nutrient and transpiration are both important in preventing blossom-end rot disease in tomato in soilless culture. Thus, mineral nutrient level i.e., EC value should be maintain for improvement of produce quality. Studies revealed that potassium and EC have positive effects on quality of vegetable crops grown in hydroponics. On the contrary, low EC found to promote quality of cut flower. Further investigation are necessary to determine the prolong reuse of the substrates and their mixtures.

The need for soilless culture arose from plant protection issues with soil-borne pathogens and environmental regulations against groundwater pollution with industrial effluents, nitrate and pesticides. Soilless substrates either having organic or inorganic ingredients have been used as for finding suitable growing media for horticultural crop production. The types of raw material used vary according to their domestic availability in the world. Raw materials variations in different substrate influence the plant growth and development directly and/or

indirectly. Thus, selection of ideal substrate from various materials is imperative for productivity of each crop (Olympios, 1999). Many substrates evolved for horticultural crops production with their cultural guidelines. From them only suitable or adapted cultural guidelines will benefits the grower in successful cultivation for his produce.

Summary

Soil-based agriculture is facing some major challenges with the advent of civilization all over the world, such as decrease productive land availability. Apart from this, due to rapid urbanization and industrialization as well as threats from climate change and its related adverse effect, the land cultivation is going to further facing challenging threats. Under such circumstances, in the near future it becomes intricate to feed the entire population using the production from soil field system. Naturally, soil-less culture is becoming more relevant in the present scenario, to cope-up with these challenges. Soilless Culture‖ is the growing of plants that imitate soil- base gardening by using many kinds of growing media as for example inorganic substance, organic substance and synthetic substrates. Soilless culture is the fastest growing sector of agriculture, and it could be impetus to food production in the future. The industry is expected to grow exponentially also in future, as conditions of soil growing becoming difficult.

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.. 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. Closed soilless system is known for better result in water use efficiency, while maintaining the quality of the yield. 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. Therefore, in conclusion, Soilless culture systems (SCSs) is the most intensive production method in today's horticulture industry, are based on environmentally friendly technology, which can result in higher yields, higher quality and even in areas with adverse growing conditions.

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