

Editorial

Advances in Soilless Culture and Growing Media in Today's Horticulture—An Editorial

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Abstract: The soilless culture system is a promising, intensive, and sustainable approach with various advantages for plant production. The Special Issue “Soilless Culture, Growing Media, and Horticultural Plants” includes 22 original papers and 1 review written by 84 authors from 15 countries. The purpose of this Special Issue was to publish high-quality research articles that address the recent developments in the cultivation of horticultural plants in soilless culture systems and solid growing media. The published articles investigated new developments in simplified and advanced systems; the interaction between soilless and environmental factors with their effects on plant growth and photosynthesis, and the accumulation of secondary metabolites; the analyses of nutrient solution and hydraulic properties of substrates and mixtures; and the microbe–plant growing media interactions. Climate change and environmental and ecological issues will determine and drive the development of soilless culture systems and the choice of growing media constituents in the near future. Bioresources and renewable raw materials have great potential for use as growing medium constituents.

1. Introduction

Decreasing arable land, rising urbanisation, water scarcity, and climate change have placed pressure on agricultural producers [1]. The soilless culture system (SCS) is a promising approach with different advantages for plant production. As an intensive and sustainable cultivation method, SCSs have rapidly expanded worldwide, particularly in areas close to cities or with a shortage of water supply, poor soil quality, and problems with soil-borne diseases and salinity. These systems produce pot ornamentals, seedlings, and transplants and increase plant metabolites in fruits, vegetables, and medicinal and aromatic plants. Production technology affects plant growth, yield, and overall plant quality, which, in turn, improves the cumulative benefits of plants [2–4].

Horticultural crops, such as vegetables, floral crops, ornamentals, and fruits, have become essential components of aesthetics and nutrition in our daily life. Currently, SCSs have received significant interest and are used for the intensive production of vegetables, floral crops, ornamentals, green roofs, and rain gardens [2,3,5]. Furthermore, because of their lightweight and sustainable resource efficiency, soilless systems are especially suitable for urban areas, including green infrastructure projects and vertical farming [6]. The increased worldwide production of crops in controlled environmental systems has been further accelerated by the increased interest in growing small/soft fruit crops, greens, herbs, and cannabis in soilless container systems. In addition, they are used to increase metabolites in medicinal and aromatic plants and to introduce new crops [2,3]. As a result, the demand for SCS and growing media continues to increase worldwide, as does the need for novel research to address problems and continue creating opportunities for this industry [4].

The purpose of this Special Issue was to publish high-quality research articles that address the recent developments in the cultivation of horticultural plants using SCSs with or without solid growing media. It aims to provide contributions from various currently relevant topics in horticultural sciences, physiology, root medium properties,



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plant propagation, plant nutrition and chemistry, substrate hydrology and physics, compost and waste management, engineering, and all other research fields familiar with soilless culture and growing media.

The Special Issue “Soilless Culture, Growing Media, and Horticultural Plants” includes 22 original papers and 1 review written by 84 authors from 15 countries. Considering this is just the tip of the iceberg, the remaining papers were rejected during the published review process, showing the great interest in this Special Issue from the scientific community. Writing an editorial after several years allowed us to analyse the papers’ importance. Following citations from the publication date until the end of October 2022, papers from this Special Issue were cited 363 times, with an average of 16.5 times per paper, which is relatively high. The review article [1] received the highest number of citations (126) among all the published papers. It should be mentioned that this article received the second-best paper award on the tenth anniversary of the journal, while the Web of Science-Clarivate lists it as a highly cited paper (1% of all papers included in the database). The article from Dou et al. [7] received the highest number of citations among the research papers, with 41 citations.

2. Soilless Culture Systems

Soilless culture is a modern cultivation technology applied mainly in greenhouses, which has developed rapidly during the last 30–40 years [5]. Most SCS plants are grown in high-tech greenhouse structures with fully automatic climate control features [2,3]. This Special Issue focused on new developments in simplified, advanced, and complex SCSs. For instance, Bentrarty et al. [8] and Michelon et al. [9] investigated the feasibility of a low-tech SCS for cultivating *Pelargonium zonale* and *Lactuca sativa*, respectively. As a result, the yield for lettuce cultivation in tropical areas was improved by +35% and +72% in Brazil and Myanmar, respectively, and the water-use efficiency (WUE) was 7.7 and 2.7 times higher in Brazil and Myanmar, respectively, compared to traditional on-soil cultivation [9]. The soilless system typology can also significantly affect the rooted cutting growth, commercial features, and WUE. For example, adopting an open-cycle drip system significantly improved all commercial crop characteristics of geranium (*Pelargonium zonale*) compared to a substrate and a nutrient film technique system. The water consumption of this treatment system was higher than that of the other systems. However, it induced the highest fresh weight and, therefore, the highest WUE [8].

Given its flexibility in manipulating the nutrient status and efficient utilisation of nutrient components, SCSs could be used as an efficient tool for producing high-value vegetables and herbs and crucial root vegetables in temperate and tropical zones, such as sweetpotatoes (*Ipomoea batatas*) [10].

In recent years, research on soilless culture has mainly focused on the automation of nutrient and water supply, particularly in closed systems [5]. A closed-loop SCS is an environment-friendly cultivation method. However, variations in nutrients can lead to instability in nutrient management. Ahn and Son [11] analysed nutrient variation in a closed-loop SCS based on a theoretical model and found fluctuations around the target value. However, the total nutrient concentration did not continuously deviate from the target value in the conventional method and showed a tendency to increase. Therefore, the authors concluded that these characteristics of the alternative method could help minimise nutrient and water emissions from the cultivation system.

Theoretical and experimental analyses of nutrient solutions, variations in electrical conductivity, fertiliser selection, and nutrient solution replenishment methods have been discussed in the papers published in this Special Issue. The fertiliser used in the SCS should contain balanced elements without any precipitates [12]. For sweet pepper yields, the commercial fertiliser 5N-4.8P-21.6K was responsible for the highest yield of both cultivars, ‘Bentley’ and ‘Orangella’. Fertilisers and cultivars did not affect the shape index. For eggplant, the shoot fresh weight was greater for ‘Angela’ than for ‘Jaylo’ at 5N-4.8P-21.6K and 7N-3.9P-4.1K. Furthermore, both eggplant cultivars were affected by yellowing fruits

for all the fertiliser treatments after two months, probably due to the accumulation of nutrients in the closed hydroponic system [12].

3. The Interaction of SCS with Environmental Greenhouse Factors

The effects of the interaction of soilless culture and different environmental greenhouse factors, such as supplemental lighting intensity, UV radiation, and CO₂ enrichment, on biomass accumulation, gas exchange properties, and plant quality are addressed in this Special Issue. For instance, Llewellyn et al. [13] found that increasing levels of supplemental light had only minor effects on vegetative growth (young plants) and the size and quality of harvested flowers (mature plants). However, cut gerbera (*Gerbera jamesonii*) plants grown under higher light intensity produced 10.3 and 7.0 more total and marketable flowers per plant than the lowest light intensity and matured faster [13].

One other factor is the CO₂ concentration in the air. According to Li et al. [14]), the accumulation of cucumber biomass can be significantly increased by elevated CO₂ concentrations and high N supply. In addition, a high N supply can further improve photosynthesis. The authors concluded that if we had a greater understanding of the mechanisms that control mineral concentration changes in cucumber plants in response to elevated CO₂, mineral fertilisation could be optimised to improve the growth of plants under elevated CO₂ conditions. Thus, sustainable vegetable production with higher C and N use efficiency and lower CO₂ emissions and fertiliser input could be achieved [14].

4. SCS and Produce Quality

Using SCSs to control nutrients, the temperature in the root area, and managing environmental and agronomic factors can improve product quality [1,15]. This Special Issue investigated the effects on plant photosynthesis and growth, the accumulation of secondary metabolites, and seasonal antioxidant changes. For instance, Neocleous et al. [16] indicated that lower solar irradiance, ultraviolet radiation, and temperature in Mediterranean greenhouses could be insufficient to stimulate phytochemical production during late autumn and winter in peppers. Thus, plant light interception must be more actively managed. Furthermore, Ellenberger et al. [17] investigated how stress affects the content of secondary metabolites in leaf bell papers. Therefore, high UV stress should be considered a tool for enriching plant leaves with valuable secondary metabolites.

The absence of ultraviolet (UV) radiation and low photosynthetic photon flux density (PPFD) in a controlled environment reduced the phenolic compounds in herbs. Dou et al. [7] investigated green and purple basil to characterise the optimal UV-B radiation dose and PPFD for enhancing the synthesis of phenolic compounds in basil plants (*Ocimum basilicum*). Plants were grown at two PPFDs, 160 and 224 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$, and treated with five UV-B radiation doses. In purple basil plants, the concentrations of phenolics and flavonoids increased after 2 $\text{h}\cdot\text{d}^{-1}$ of UV-B treatment. Among all treatments, 1 $\text{h}\cdot\text{d}^{-1}$ for 2 d of UV-B radiation under a PPFD of 224 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ was the optimal condition for green basil production in a controlled environment [7].

Interestingly, Giménez et al. [18] found that compost in growing media boosted the product's final quality, with a higher total phenolic content and antioxidant capacity in the leaves of baby leaf lettuce in a floating system, particularly during the second cut.

5. Growing Media and the Diversity of Inorganic and Organic Substrates

In SCSs, solid inorganic or organic substrates are used for plant cultivation, usually in containers. Therefore, studies submitted to this Special Issue have investigated the physicochemical and hydraulic properties of organic and mineral substrates and mixtures and the substrate volumetric water content to improve water-use efficiency in growing media. Furthermore, the chemical properties and the microbe–plant growing media interactions were investigated.

According to Gohardoust et al. [19], an essential first step towards developing advanced soilless culture management strategies is the comprehensive characterisation of

the growing media's hydraulic and physicochemical properties. These parameters can be applied to the engineering of growing media by mixing organic and inorganic constituents at different ratios to meet specific plant physiological demands. Furthermore, these results could also be used to visualise three-dimensional numerical computer codes to simulate water and nutrient dynamics in containerised growth modules.

Moreover, Currey et al. [20] found that the growth of basil, dill, parsley, and sage can be affected by the water supply, with no signs of stress or visual damage resulting from the reduced volumetric water content of the substrate. Therefore, restricting irrigation and substrate volumetric water content is an effective non-chemical growth control method for containerised culinary herbs.

Bacterial enhancement has a significant potential to modulate plant performance in horticultural systems. However, the effectiveness of bacterial amendment regarding plant performance depends on the bacterial source and its interaction with the growth medium. Therefore, an appropriate selection of the plant growth medium composition is critical for the efficacy of bacterial amendments and optimal plant performance in a plant factory with artificial lighting [21].

6. Peat Alternatives in Growing Media Mixtures

Peat is the most commonly used substrate constituent in horticulture. However, the use of peat in horticulture has been strongly criticised because of environmental and climate change concerns [1–3]. Therefore, new peat additives and/or peat alternative growing media, such as biochar, green compost, olive oil-processing waste composts, and vermicompost, were investigated in the Special Issue. In addition, the raw materials used as growing media constituents should be free from phytotoxic compounds [22] and should demonstrate good chemical properties, such as a suitable pH [23,24] and the content of certain elements and/or salt content [18,25].

Composts from different raw materials, such as vineyard waste, tomato waste, leek waste, and olive mill cake, can be alternatives to peat in producing baby leafy vegetables in a floating system. The use of 25% compost as a component of the growing media in the production of baby leafy vegetables in a floating system not only favours crop yield and product quality, but also suppresses *Pythium irregulare* [18].

Tüzel et al. [26] found that compost obtained from two-phase and three-phase olive mill solid wastes and olive oil wastewater sludge that can be used in a ratio of 25% in mixtures with peat was appropriate for most of the measured tomato seedling properties.

Moreover, biochar has been proposed as a soil amendment and a growing medium component that positively affects plant growth and yield [24]. Chrysargyris et al. [25] investigated four types of commercial-grade biochar from wood-based materials used in mixtures with peat for cabbage seedling production. Biochar material had a high K content and a pH ≥ 8.64 , which increased the growing media's pH. In addition, the leachate pH of all biochar mixes was higher than that of the control [27]. Potassium, phosphorous, copper accumulation and magnesium deficiency in cabbage leaves were related to the presence of biochar. Therefore, wooden biochar from beech, spruce, and pine species and fertilised biochar from fruit trees and hedges is promising for cabbage seedling production [25].

While recent studies on biochar mentioned the importance of the feedstock used, Prasad et al. [24] stated for the first time the need for information on particle size because the fractions from the same biochar can have different levels of total extractable nutrients and pH levels. Particle size could have a profound effect on the nutrient availability of Ca and Mg. This could lead to nutrient imbalances during the cultivation of plants on substrate mixtures. In addition to nutrient ratios, a suitable pH level for a given species should be achieved [24].

Mixes with 80% biochar and vermicompost had lower container capacities than the control. Nevertheless, plants in the BC mixes had similar growth indices and total dry weights concerning those in 100% commercial substrate. Therefore, BC mixed with vermi-

culite has the potential to replace commercial peat-based substrates for container-grown plants [27].

Yu et al. [28] conducted a greenhouse experiment to evaluate the potential of replacing mixed hardwood biochar with sugarcane bagasse. Both tomato and basil plants grown in biochar-incorporated mixes had a similar or higher growth index, leaf greenness, and yield than bark-based commercial substrates. The authors concluded that hardwood and sugarcane bagasse biochar could replace 50% and 70% of bark-based substrates for tomato and basil plants without adverse growth effects [28].

7. Concluding Remarks and Future Trends

The articles published in this Special Issue stated that climate change and environmental and ecological issues would soon determine and drive the development of soilless cultural systems and the choice of growing media constituents. It is clear that while much has been achieved in this Special Issue, many challenges remain. Understanding the optimisation of root-zone conditions [29] and clarifying the mechanism of interaction between roots and surroundings will contribute to a better understanding of SCS. Advances in soilless culture will be supported by findings from other scientific fields that will contribute to the further development of soilless cultures. In addition, bioresources and renewable raw materials have great potential for use as growing media constituents. We expect these publications to promote further discussion about these two exciting topics.

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