horticulturae

Editorial

Is Soilless Culture a Sustainable Form of Agriculture?

Nazim S. Gruda [1,*], Rui M. A. Machado [2] and Erik A. van Os [3]

1 INRES—Institute of Crop Science and Resource Conservation, Department of Horticultural Sciences, University of Bonn, 53121 Bonn, Germany
2 MED—Mediterranean Institute for Agriculture, Environment and Development & CHANGE—Global Change and Sustainability Institute, Crop Science Department, School of Sciences and Technology, University of Évora, Pólo da Mitra, Ap. 94, 7006-554 Évora, Portugal; rmam@uevora.pt
3 Business Unit Greenhouse Horticulture, Wageningen University and Research, Droevendaalsesteeg 1, 6708 PB Wageningen, The Netherlands; erikhydroponic@gmail.com
* Correspondence: ngruda@uni-bonn.de

Citation: Gruda, N.S.; Machado, R.M.A.; van Os, E.A. Is Soilless Culture a Sustainable Form of Agriculture? *Horticulturae* **2023**, *9*, 1190. https://doi.org/10.3390/horticulturae9111190

Received: 26 October 2023
Accepted: 27 October 2023
Published: 31 October 2023

1. Introduction

A soilless culture system (SCS) is a technique used for plant production that has recently become increasingly popular [1,2]. For instance, almost all greenhouse areas in the Netherlands use SCSs due to their benefits, including up to 50% savings on water and fertilisers, the ability to steer crop growth vegetatively or generatively, and higher yields with better quality [3–5]. Similar systems with low investments can be used in mid- and low-tech horticulture. SCSs also enable growers to start with a disease-free crop; crop rotation is no longer required [5]. Further, it significantly benefits regions facing water scarcity, unfavourable soil conditions, infertility, soil-borne diseases, salinity, or sodicity [1,2,6]. Especially when water shortage is an issue, circulating surplus nutrient solutions can save water and expensive fertilisers. Alternatively, the surplus can be used in another crop without recirculating [4]. The primary goal is intensification. Thus, an SCS is employed in areas with suitable climate conditions and proximity to major urban centres to ensure and increase productivity.

Diverse crops require varied growing techniques. A growing medium with 30% drainage is utilised for fruit vegetables, accommodating 2–10 plants per square meter. This medium is sterilisable for reuse. NFT or DFT techniques are commonly used for leafy crops like lettuce and kale, sometimes with fixed or movable troughs. The nutrient solution is continuously circulated in this method. Growing media also serve to cultivate herbaceous plants, ornamentals, medicinal and aromatic species, small fruits, and woody crops. Seedlings and transplants are produced using these media in controlled and open agricultural environments [7]. Nevertheless, there is an ongoing discussion regarding the sustainability of SCS and growing media [8,9].

Reducing or replacing the use of peat, improving nutrient and water efficiency, and establishing circular waste flows are crucial steps towards the sustainable cultivation of soilless plants. By utilising renewable and locally available raw materials, appropriate substrate mixtures, biostimulants, and advanced techniques such as artificial intelligence and the Internet of Things, we can develop a new strategy for SCSs. These measures have the potential to pave the way for a promising future for agriculture.

The Special Issue, titled "Soilless Culture—An Intensive Production Method on Its Way to Sustainability", includes recent research on sustainable horticultural plant cultivation using SCSs. It features contributions from diverse experts spanning circular growing media, remote growing, cost-effective methods for increasing profitability, biostimulants, plant nutrition, and water quality. This Special Issue includes 10 original contributions written by 42 authors from 9 countries.

2. Alternative Peat-Growing Media

The utilisation of peat substrates is the basis of today's growing media in horticulture. Regrettably, peat extraction can damage the environment and ecosystems. Peatlands serve as natural carbon sinks, and using peat as a substrate releases stored carbon, negatively impacting the CO_2 balance and contributing to global warming [1,2]. As a result, the shift from peat to sustainable alternatives in horticultural growth is of utmost importance [1,2,10]. However, this presents a significant challenge due to peat's physical and chemical characteristics. Nevertheless, it is paramount for the horticultural industry to adopt sustainable practices, and reducing or eliminating peat from growing media cannot be disregarded [8]. This Special Issue highlights the significance of transitioning towards sustainable horticultural practices, the difficulties faced, and various strategies to reduce or eliminate peat usage in the growing media industry through a collection of papers.

The first contribution of this Special Issue focuses on replacing peat in horticultural growing media with alternative constituents based on biomass. Using four well-established non-peat materials, namely wood fibre, bark, composted green waste, and coir, has garnered considerable attention in agriculture. Each material presents distinct challenges and possesses specific properties. For instance, wood fibre may lead to nitrogen immobilisation, while composted green waste and bark can exhibit high bulk density and electrical conductivity (EC). However, these materials also offer significant nutrient content, distinguishing them from peat-based alternatives.

It is crucial to emphasise the varying roles of these materials in peat replacement. For instance, it is recommended to use wood fibre as a compound and diluent in growing media; some studies have demonstrated that it can even be utilised alone [1]. Composted bark and coir have the potential to function as complete replacements for peat. Contribution 1 emphasised the sustainability aspects of using no peat materials in the future, underscoring the significance of sustainable agricultural practices in line with the focus of this Special Issue, analysing factors affecting the supply and use of growing media constituents in Germany, including processing infrastructure, competition, and the economic advantage of peat. Although technical solutions for peat-free media exist, this study suggests future evolutions will not lead to the complete substitution of peat in Germany (contribution 1).

Martins et al. (contribution 2) conducted a study on using coir, municipal compost, and biochar to reduce peat content in growing media. They found that lettuce seedlings grown in coir-based media with 17–22% v/v of municipal solid waste compost and biochar grew more vigorously than in other mixtures. The mixes also increased the total phenol content in lettuce leaves, which can improve abiotic stress tolerance. However, further research is needed to evaluate how the seedlings behave after transplantation and to compare these mixes with commercial counterparts for different vegetable transplants [10].

Česonienė et al. (contribution 3) studied a different aspect. They investigated the impact of substituting peat with varying proportions of pine and spruce wood fibres and perlite on the growth of blueberry saplings. The study found that the most favourable outcomes were observed with substrates containing 15–45% v/v of pine wood fibre and 15–30% v/v of spruce wood fibre. Conversely, introducing spruce bark fibres over 30% had a detrimental effect on sapling growth. Analysis of leaf macronutrients revealed challenges, particularly in nitrogen and potassium levels, within substrates containing 30–45% v/v of spruce bark fibres. These findings underscore the potential to reduce peat consumption while supporting the conservation of vital wetland ecosystems (contribution 3).

The utilisation of organic fertilisers in soilless container plant production has increased. However, there is a shortage of techniques to evaluate N release. The release of mineralisable N can be estimated using water-soluble and hydrolysable N and C pools. The Gompertz function is a reliable method for making precise estimations. Nonetheless, this research underscores two primary obstacles confronting agricultural practitioners when utilising organic nitrogen-based fertilisers: firstly, the nitrogen release comprises only 50% of the total nitrogen applied, and secondly, this release transpires swiftly, resulting in salt-induced damage and rendering complete nitrogen application before planting becomes unfeasible (contribution 4).

3. Cascade Systems

In the realm of cascade systems, which prioritise resource efficiency and sustainability, various studies have demonstrated their effectiveness in optimising nutrient and growing medium utilisation.

As exemplified in a study by Karatsivou et al. (contribution 5), soilless cascade systems are highly proficient in recycling nutrient solutions. This innovative prototype, designed to repurpose drained nutrient solutions from primary tomato crops for secondary crops, yielded a 14% increase in spinach yield. When lettuce and parsley were used as secondary crops, their yield remained unaffected by the system. Furthermore, the environmental advantages were evident as water productivity improved with pure drainage solutions, and there was a remarkable 50% increase in nitrogen and phosphorus use efficiency compared to control treatments.

Similarly, the concept of reusing the substrate of a primary crop for a secondary crop has gained traction in cascade systems. In a study by Machado et al. (contribution 6), various coir-based mixtures were tested for growing spinach. The lettuce plants grown in the reused mixtures exhibited yields similar to those produced in new coir, demonstrating the viability of such practices. These findings underscore the potential of soilless cascade systems to optimise nutrient and growing medium utilisation, thereby reducing the need for supplementary fertilisers or plant substrates, ultimately contributing to environmental sustainability (contributions 5 and 6).

Expanding the scope of cascade cropping systems, contribution 7 explored the feasibility of incorporating biodegradable packaging within the short food supply chain. Specifically, they assessed the impact of replacing conventional petroleum-based bags with PLA film on the shelf life of fresh-cut wild rockets (primary crop) and sea fennel (secondary crop). This study found that using PLA-based film had no significant detrimental effects after storage and demonstrated superior microbiological safety compared to conventional materials. These findings suggest that integrating biodegradable materials like PLA film could further enhance the sustainability of cascade cropping systems, offering an eco-friendly alternative to petroleum-based plastics within a short food supply chain. In this way, cascade systems continue to evolve as a vital component of sustainable agricultural practices.

Greenhouse agriculture faces significant challenges in terms of environmental sustainability, particularly regarding pesticide emissions from crops grown in open or closed systems. To address this issue, contribution 8 tested a greenhouse emission model using stone wool mats for sweet pepper cultivation via drip irrigation. They improved the model's performance by modelling the mats as two equally large tanks. Furthermore, exploring alternative pesticide application methods like spraying or low-volume misting is essential in pursuing environmentally friendly practices, which involve additional processes affecting substance entry into recirculation water.

Examining sustainable agricultural practices, contribution 9 researched the use of sodium hypochlorite as a disinfectant for tomato plants cultivated in recycled nutrient solutions. Surprisingly, this study found that chlorine application did not negatively impact plant growth or gas exchange; instead, it significantly increased the total production of marketable fruits. Tomatoes grown in this manner are safe to consume. However, it is important to note that further research is required to assess the effectiveness of chlorine as a disinfectant in nutrient solutions, especially when combined with crop inoculation against pathogens.

Demonstrating the commitment to environmentally responsible SCS, contribution 10 conducted research that showcased the advantages of integrating mycorrhiza and bacteria alongside 80% mineral fertilisers in capia pepper cultivation. This approach resulted in a remarkable 32.4% increase in yield compared to using 100% mineral fertilisers alone.

Beyond yield, the plants treated with bio-fertilisers exhibited superior fruit parameters, including fruit weight, diameter, volume, electric conductivity of fruit juice, and total soluble solids. These findings provide compelling evidence that incorporating bacteria and mycorrhiza into farming practices can reduce reliance on mineral fertilisers and promote a more sustainable approach to horticulture (Dasgan et al.).

4. Conclusions

SCSs have the potential to enhance water and nutrient utilisation efficiency significantly. However, several aspects of the SCS production process require improvement to improve sustainability.

In pursuit of sustainable agriculture practices, this Special Issue explores alternative biomass-based constituents to replace peat in horticultural growing media. Through the evaluation of four established non-peat materials, namely wood fibre, bark, composted green waste, and coir, the authors of this Special Issue uncover specific advantages and challenges associated with each. Wood fibres emerge as a potential compound or diluent, while composted bark and coir show promise as peat substitutes. Sustainability is a focal point, yet supply and complete peat substitution challenges persist.

Cascade systems represent a substantial leap forward in enhancing sustainability within agriculture. Their multifaceted approach, which encompasses recycling nutrient solutions, minimising pesticide emissions, and integrating eco-friendly practices, holds great promise for the future of farming. These innovative solutions optimise resource utilisation and contribute significantly to promoting environmentally responsible agricultural practices. The results from this Special Issue will contribute to advancing our understanding of cascade systems and their potential to transform agriculture into more sustainable and ecologically mindful efforts. As we face the challenges of a changing world, cascade systems provide a ray of hope for a more sustainable and resilient agricultural future.

In summation, the outcomes of diverse studies within this Special Issue underscore the potential of SCS as a viable form of sustainable agriculture. These investigations accentuate a range of strategies aimed at fortifying the sustainability of SCS, encompassing a reduction in peat use in horticulture, the implementation of efficient nutrient management protocols, the adoption of cascading systems for recycling nutrient solutions, the reuse of GM, and the incorporation of bio fertilisers, among others. Nonetheless, it is imperative to underscore further research in this domain, as it is pivotal for refining and seamlessly integrating these strategies into SCS. This integration should happen by stimulating the yield and quality of horticultural products.

Author Contributions: N.S.G. drafted the manuscript outline and analysed the Special Issue topics. E.A.v.O. contributed to the introduction, while R.M.A.M. contributed to the concluding remarks and future perspectives and formatted the manuscript according to the journal's guidelines. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

List of Contributions

1. Hirschler, O.; Thrän, D. Peat Substitution in Horticulture: Interviews with German Growing Media Producers on the Transformation of the Resource Base. Horticulturae, 2023, 9(8), 919. https://doi.org/10.3390/horticulturae9080919
2. Martins, T.C.; Machado, R.M.A.; Alves-Pereira, I.; Ferreira, R.; Gruda, N.S. Coir-Based Growing Media with Municipal Compost and Biochar and Their Impacts on Growth and Some Quality Parameters in Lettuce Seedlings. Horticulturae, 2023, 9(1), 105. https://doi.org/10.3390/horticulturae9010105
3. Česonienė, L.; Krikštolaitis, R.; Daubaras, R.; Mažeika, R. Effects of Mixes of Peat with Different Rates of Spruce, Pine Fibers, or Perlite on the Growth of Blueberry Saplings. Horticulturae, 2023,9(2), 151. https://doi.org/10.3390/horticulturae9020151

4. Lohr, D.; Gruda, N.S.; Meinken, E. Estimating Nitrogen Release from Organic Fertilizers for Soilless Production by Analysis of C and N Pools. Horticulturae, 2023, 9(7), 767. https://doi.org/10.3390/horticulturae9070767
5. Karatsivou, E.; Elvanidi, A.; Faliagka, S.; Naounoulis, I.; Katsoulas, N. Performance Evaluation of a Cascade Cropping System. Horticulturae, 2023, 9(7), 802. https://doi.org/10.3390/horticulturae9070802
6. Machado, R.M.A.; Alves-Pereira, I.; Alves, I.; Ferreira, R.M.; Gruda, N.S. Reusing Coir-Based Substrates for Lettuce Growth: Nutrient Content and Phytonutrients Accumulation. Horticulturae, 2023, 9(10), 1080. https://doi.org/10.3390/horticulturae9101080
7. Gómez, P.A.;Egea-Gilabert, C.; Giménez, A., Benaissa, R.R.,;Amoruso, F.; Signore, A.; Gallegos-Cedilo, V.; Ochoa, J.; Fernández, J.A. Biodegradable Food Packaging of Wild Rocket (*Diplotaxis tenuifolia* L.[DC.]) and Sea Fennel (*Crithmum maritimum* L.) Grown in a Cascade Cropping System for Short Food Supply Chain. Horticulturae, 2023, 9(6), 621. https://doi.org/10.3390/horticulturae9060621
8. Wipfler, E.L.; Boesten, J.J.; van Os, E.A.; Beltman, W.H. Testing the Greenhouse Emission Model (GEM) for Pesticides Applied via Drip Irrigation to Stone Wool Mats Growing Sweet Pepper in a Recirculation System. Horticulturae, 2023, 9(4), 495. https://doi.org/10.3390/horticulturae9040495
9. Lykogianni, M.; Bempelou, E.; Karavidas, I.; Anagnostopoulos, C.; Aliferis, K.A.; Savvas, D. Impact of sodium hypochlorite applied as nutrient solution disinfectant on growth, nutritional status, yield, and consumer safety of tomato (*Solanum lycopersicum* L.) fruit produced in a soilless cultivation. Horticulturae, 2023, 9(3), 352. https://doi.org/10.3390/horticulturae9030352
10. Dasgan, H.Y.; Yilmaz, M.; Dere, S.; Ikiz, B.; Gruda, N.S. Bio-Fertilizers Reduced the Need for Mineral Fertilizers in Soilless-Grown Capia Pepper. Horticulturae, 2023, 9(2), 188. https://doi.org/10.3390/horticulturae9020188

References

1. Gruda, N.S. Increasing Sustainability of Growing Media Constituents and Stand-Alone Substrates in Soilless Culture Systems. *Agronomy* **2019**, *9*, 298. [CrossRef]
2. Gruda, N.S. Advances in Soilless Culture and Growing Media in Today's Horticulture—An Editorial. *Agronomy* **2022**, *12*, 2773. [CrossRef]
3. Putra, A.P.; Yuliando, H. Soilless Culture System to Support Water Use Efficiency and Product Quality: A Review. *Agric. Agric. Sci. Procedia* **2015**, *3*, 283–288. [CrossRef]
4. Santos, M.G.; Moreira, G.S.; Pereira, R.; Carvalho, S.M.P. Assessing the potential use of drainage from open soilless production systems: A case study from an agronomic and ecotoxicological perspective. *Agric. Water Manag.* **2022**, *273*, 107906. [CrossRef]
5. Van der Salm, C.; Voogt, W.; Beerling, E.; Van Ruijven, J.; Van Os, E. Minimising emissions to water bodies from NW European greenhouses; with focus on Dutch vegetable cultivation. *Agric. Water Manag.* **2020**, *242*, 106398. [CrossRef]
6. Savvas, D.; Gruda, N. Application of soilless culture technologies in the modern greenhouse industry—A review. *Eur. J. Hortic. Sci.* **2018**, *83*, 280–293. [CrossRef]
7. Pascual, J.A.; Ceglie, F.; Tuzel, Y.; Koller, M.; Koren, A.; Hitchings, R.; Tittarelli, F. Organic substrate for transplant production in organic nurseries. A review. *Agron. Sustain. Dev.* **2018**, *38*, 35. [CrossRef]
8. D'Amico, A.; De Boni, A.; Palmisano, G.O.; Acciani, C.; Roma, R. Environmental analysis of soilless tomato production in a high-tech greenhouse. *Clean. Environ. Syst.* **2023**, *11*, 100137. [CrossRef]
9. Gonnella, M.; Renna, M. The Evolution of soilless systems towards ecological sustainability in the perspective of a circular economy. Is it really the opposite of organic agriculture? *Agronomy* **2021**, *11*, 950. [CrossRef]
10. Blok, C.; Eveleens, B.; van Winkel, A. Growing media for food and quality of life in the period 2020–2050. *Acta Hort.* **2021**, *1305*, 341–356. [CrossRef]